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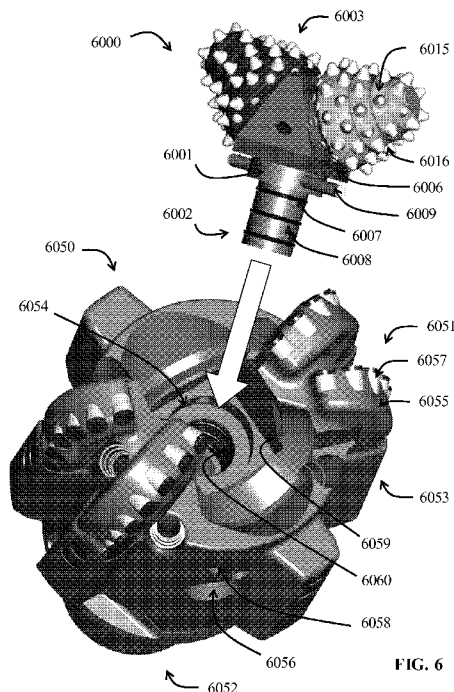


FIG. 6

(57) Abstract: A method of manufacturing a drill bit may include inserting an attachment end of a journal portion into a cavity of a blade portion. The journal portion includes the attachment end; a journal end opposite from the attachment end; and a journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion. The blade portion includes the cavity extending a distance into the blade portion; and at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit. Then, the method includes attaching the journal portion to the blade portion and mounting a roller cone to the journal.

## **MULTI-PIECE BODY MANUFACTURING METHOD OF HYBRID BIT**

### **CROSS REFERENCE TO RELATED APPLICATION**

[0001] This Application claims the benefit to and priority of U.S. Provisional Application 61/922,145 filed on December 31, 2013, the entirety of which is incorporated herein by reference.

### **BACKGROUND**

[0002] Historically, there have been two main types of drill bits used for drilling earth formations, drag bits and roller cone bits. The term “drag bits” refers to those rotary drill bits with no moving elements. Drag bits include those having cutting elements attached to the bit body, which predominantly cut the formation by a shearing action. Roller cone bits include one or more roller cones rotatably mounted to the bit body. These roller cones have a plurality of cutting elements attached thereto that crush, gouge, and scrape rock at the bottom of a hole being drilled.

[0003] Bit type may be selected based on the primary nature of the formation to be drilled. However, many formations have mixed characteristics (i.e., the formation may include both hard and soft zones), which may reduce the rate of penetration of a bit (or, reduce the life of a selected bit) because the selected bit is not as desirable for certain zones. For example, both milled tooth roller cone bits and PDC bits can efficiently drill soft formations, but PDC bits will often have a rate of penetration several times higher than roller cone bits.

#### **Drag Bits**

[0004] Drag bits, often referred to as “fixed cutter drill bits,” include bits that have cutting elements attached to the bit body, which may be a steel bit body or a matrix bit body formed from a matrix material such as tungsten carbide surrounded by a binder material. Drag bits may generally be defined as bits that have no moving parts. However, there are different types and methods of forming drag bits that are known in the art. For example, drag bits having abrasive material, such as diamond, impregnated into the surface of the material which forms the bit body are commonly referred to as “impreg” bits. Drag bits having cutting elements made of an ultra hard cutting surface layer or “table” (often made of

polycrystalline diamond material or polycrystalline boron nitride material) deposited onto or otherwise bonded to a substrate are known in the art as polycrystalline diamond compact (“PDC”) bits.

[0005] PDC bits drill soft formations easily, but they may frequently be used to drill moderately hard or abrasive formations. They cut rock formations with a shearing action using small cutters that do not penetrate deeply into the formation. Because the penetration depth is shallow, high rates of penetration are achieved through relatively high bit rotational velocities.

### **Roller Cone Drill Bits**

[0006] Roller cone drill bits may be used to drill formations that fail more efficiently by crushing and gouging as opposed to shearing. Roller cone drill bits are also used for heterogeneous formations that initiate vibration in drag bits. Roller cone drill bits include milled tooth bits and insert bits. Milled tooth roller cone bits may be used to drill relatively soft formations, while insert roller cone bits are suitable for medium or hard formations. Roller cone drill bits include a bit body with a threaded pin formed on the upper end of the bit body for connecting to a drill string, and one or more legs extending from the lower end of the bit body. The threaded pin end is adapted for assembly onto a drill string for drilling oil wells or the like. Roller cone bits may have better steerability when building curve section of a wellbore.

### **Hybrid Drill Bits**

[0007] Both roller cone and drag bits have their own advantages. Due to the difference in cutting mechanisms and cutting element materials, they are best suited for different drilling conditions. Roller cone bits predominantly use a crushing mechanism in drilling, which gives roller cone bits overall durability and strong cutting ability (particularly when compared to previous bit designs, including disc bits). Drag bits use a shearing mechanism for cutting, which allows higher performance in soft formation drilling than roller cone bits are able to achieve.

[0008] Thus, in drilling operations facing mixed formations, using one type of drill bit over the other may not be adequate for the entire operation. Hybrid drill bits that use a combination of one or more rolling cutters and one or more fixed blades have been proposed previously.

However, problems arise during the design of these hybrid bits in trying to combine rolling cutters and fixed blades within a limited amount of space.

## SUMMARY

[0009] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0010] In one aspect, embodiments disclosed herein relate to a method of manufacturing a drill bit that includes inserting an attachment end of a journal portion into a cavity of a blade portion. The journal portion includes an attachment end; a journal end opposite the attachment end; and at least one journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion. The blade portion includes a cavity extending a distance into the blade portion; and at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit. Upon insertion of the journal portion into the blade portion, the method further includes inserting the journal portion into the cavity of the blade portion; attaching the journal portion to the blade portion; and mounting a roller cone to each of the at least one journal.

[0011] In another aspect, embodiments disclosed herein relate to a method of manufacturing a drill bit that includes determining a primary torque transfer area between a journal portion and a blade portion of a multi-piece bit body and inserting an attachment end of the journal portion into a cavity of the blade portion to form the multi-piece bit body. The journal portion includes the attachment end; a journal end opposite from the attachment end; at least one journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion; and a locking segment formed of a plurality of intersecting outer side surfaces around the journal portion between the attachment end and the journal end. A total outer side surface area of the locking segment is equal to or greater than the primary torque transfer area. The blade portion includes the cavity extending a distance into the blade portion; and at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit.

[0012] Other aspects and advantages of the claimed subject matter will be apparent from the following description and the appended claims.

### BRIEF DESCRIPTION OF DRAWINGS

[0013] FIG. 1 shows a blade portion of a multi-piece bit body according to embodiments of the present disclosure.

[0014] FIG. 2 shows a blade portion of a multi-piece bit body according to embodiments of the present disclosure.

[0015] FIG. 3 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

[0016] FIG. 4 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

[0017] FIG. 5 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

[0018] FIG. 6 shows a journal portion being assembled to a blade portion according to embodiments of the present disclosure.

[0019] FIG. 7 shows an assembled multi-piece bit according to embodiments of the present disclosure.

[0020] FIG. 8 shows a diagram of an assembled multi-piece bit according to embodiments of the present disclosure.

[0021] FIG. 9 shows a journal portion and a corresponding blade portion of a multi-piece bit body according to embodiments of the present disclosure.

[0022] FIG. 10 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

[0023] FIG. 11 shows a journal portion and a corresponding blade portion of a multi-piece bit body according to embodiments of the present disclosure.

- [0024] FIG. 12 is a perspective view of a bit according to embodiments of the present disclosure.
- [0025] FIG. 13 is a side view of a bit according to embodiments of the present disclosure.
- [0026] FIG. 14 is a perspective view of a bit according to embodiments of the present disclosure.
- [0027] FIG. 15 shows the cutting profile of a bit according to embodiments of the present disclosure.
- [0028] FIG. 16 shows a bottom view of a bit according to embodiments of the present disclosure.
- [0029] FIG. 17 shows a side view of a bit according to embodiments of the present disclosure.
- [0030] FIG. 18 shows the cutting profile of a bit according to embodiments of the present disclosure.
- [0031] FIG. 19 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.
- [0032] FIG. 20 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.
- [0033] FIG. 21 shows orientation of a ball passageway in the Y-Z plane.
- [0034] FIG. 22 shows orientation of a ball passageway in the X-Y plane.
- [0035] FIG. 23 shows orientation of a ball passageway in the X-Z plane.
- [0036] FIG. 24 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.
- [0037] FIG. 25 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.
- [0038] FIG. 26 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

[0039] FIG. 27 shows a journal portion of a multi-piece bit body according to embodiments of the present disclosure.

## DETAILED DESCRIPTION

[0040] Embodiments of the present disclosure relate to methods of forming hybrid drill bits having both roller cones and blades. The roller cones may be radially and/or axially offset from the blades, such that the roller cone portion of the bit mainly cuts the center of a borehole and the blade portion of the bit mainly cuts the gauge portion of the borehole. For example, at least some of the cutting elements disposed on one or more blades of a bit may be positioned at gauge while each of the cutting elements disposed on the one or more roller cones of the bit may be positioned a distance inward from the gauge of the bit. By providing a roller cone cutting profile that is at least partially non-aligned with a blade cutting profile, the roller cone portion may maintain steerability of the bit and the blade portion may protect wear of the roller cone portion.

[0041] Hybrid drill bits formed using methods of the present disclosure may include a hybrid drill bit having a multi-piece bit body with a longitudinal axis extending there through, a plurality of journals proximate to the longitudinal axis, a roller cone rotatably mounted to each of the journals, and at least one blade protruding from the multi-piece bit body and extending radially and axially along the bit body from a first end to a second end, where the first end is radially farther from the longitudinal axis than at least part of the at least one journal, and where the second end is at a gauge region of the drill bit. For example, a plurality of journals may be disposed at or near the longitudinal axis of the bit, where each journal has a journal axis extending from the base of the journal through the length of the journal. A first end of a blade may be positioned a radial distance farther from the longitudinal axis of the bit than the radial distance from the longitudinal axis to the journal axis at its base. In another example, at least one journal may be positioned on a bit cutting face such that the base of the journal axis is at a first radial distance from the bit longitudinal axis and at least one blade has a first end positioned at a second radial distance from the longitudinal axis that is greater than the first radial distance but less than the radial distance from the bit longitudinal axis to the radially outermost point of the journal.

[0042] In some embodiments, methods of the present disclosure may be used to form a drill bit having a multi-piece bit body with a longitudinal axis extending there through, at least one blade protruding from the multi-piece bit body, where the at least one blade extends an axial distance along a gauge of the multi-piece bit body and a radial inward distance from the gauge towards the longitudinal axis, a plurality of blade cutting elements disposed on the at least one blade and forming a blade cutting profile. At least one journal extends downwardly from the multi-piece bit body, a roller cone is rotatably mounted to the at least one journal, and a plurality of roller cone cutting elements are disposed on each roller cone and form a roller cone cutting profile, where the roller cone cutting profile radially extends from a first end to a second end located a radial distance inward from the gauge. The blade cutting profile may radially overlaps with the roller cone cutting profile.

[0043] In some embodiments, methods of the present disclosure may be used to form a drill bit having a multi-piece bit body with a longitudinal axis extending there through, a bit radius measured from a gauge of the bit to the longitudinal axis, at least one blade protruding from the multi-piece bit body. The at least one blade extends an axial distance along the gauge of the multi-piece bit body and a radial inward distance from the gauge towards the longitudinal axis. A plurality of journals extend downwardly from the multi-piece bit body, and a roller cone is rotatably mounted to each of the journals. The radial inward distance ranges from 1/3 to 3/4 of the bit radius.

[0044] According to some embodiments, methods of the present disclosure may be used to form a hybrid drill bit having a multi-piece bit body with a longitudinal axis extending there through, at least one blade protruding from the multi-piece bit body, where the at least one blade extends an axial distance along a gauge of the multi-piece bit body and a radial inward distance from the gauge towards the longitudinal axis. At least one journal extends downwardly from the multi-piece bit body, where the at least one journal extends a length from a base of the journal, and a roller cone is rotatably mounted to each of the at least one journal. The lowest axial point of the at least one blade is axially lower than the lowest axial point of the base of the journal. In some embodiments having the lowest axial point of a blade that is axially lower than the lowest axial point of the base of the journal, the blade may axially overlap the lowest axial point of the base of the journal. In other embodiments having the lowest axial point of a blade that is axially lower than the lowest axial point of the



base of the journal, the journal may be inset within the bit such that the blade does not axially overlap the lowest axial point of the base of the journal.

[0045] Methods of manufacturing a drill bit according to embodiments of the present disclosure include obtaining or forming components of a multi-piece bit body and assembling the components. For example, in some embodiments, methods include forming a journal portion and a blade portion of a multi-piece bit body. The journal portion has an attachment end, a journal end opposite from the attachment end, and at least one journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion. The blade portion has a cavity extending a distance into the blade portion and at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit. The journal portion may be inserted into the cavity of the blade portion and attached to the blade portion. A roller cone may be rotatably mounted to each of the journals extending from the journal portion, either before the journal portion is inserted into the cavity of the blade portion or after the journal portion is inserted into the cavity of the blade portion.

[0046] Blade portions of a multi-piece bit body may be formed from a matrix material or a steel material. For example, according to some embodiments, a blade portion may be formed of steel having 0.15-0.35% carbon by weight, from 0.15-0.2% carbon by weight, or 0.25-0.35% carbon by weight. In some embodiments, a blade portion and blades protruding from the blade portion may be integrally formed together from a steel material, such as 4130 steel, the blade portion including a nozzle bore, a reservoir for lubricant or grease, cutter pockets formed along the blades, a locking pin hole, and a cavity for receiving the journal portion. Blade portions formed of steel may have certain features milled or machined into a desired shape. For example, the shape of the cavity walls may be machined to have particular dimensions and angles of intersection. Further, blades integrally formed with a steel blade portion may be machined into a desired shape.

[0047] In some embodiments, the blade portion may be formed of a matrix material, such as a carbide hard phase, e.g., one or more transition metal carbides such as tungsten carbide, disposed in binder phase, e.g., one or more metals selected from Group VIII of the Periodic Table. Blade portions formed of a matrix material may be formed in a mold, such as by pouring a powdered mixture of matrix material into a mold having the negative shape of a blade portion, which may then be infiltrated with an infiltrant or heated to a temperature

sufficient to melt the binder phase. For example, an infiltrant, or metallic binder material, are placed over the matrix powder packed in the mold, and the components within the mold are then heated in a furnace to the flow or infiltration temperature of the infiltrant, at which point the melted infiltrant infiltrates the powdered matrix material. Once cooled, the infiltrant material may form a binder phase of the matrix material. The infiltration process that occurs during heating bonds the grains of matrix material to each other and to the other components to form a solid bit body that is relatively homogeneous throughout. The matrix powder may be a powder of a single matrix material such as tungsten carbide, or it may be a mixture of more than one matrix material such as different forms of tungsten carbide, e.g., macrocrystalline tungsten carbide, cast tungsten carbide, carburized (or agglomerated) tungsten carbide, and cemented tungsten carbide. In some embodiments, non-tungsten carbides of vanadium, chromium, titanium, tantalum, niobium, silicon, aluminum or other transition metal carbides may be used. In yet other embodiments, carbides, oxides, and nitrides of Group IVA, VA, or VIA metals may be used. Further, a matrix powder may include additional components such as metal additives. A binder phase may be formed from a powder component mixed in with the powdered matrix material and/or from an infiltrating component, such as cobalt, nickel, iron, chromium, copper, molybdenum, their alloys, or combinations thereof. For example, in some embodiments, a graphite mold may be packed with a tungsten carbide powder, which may then be infiltrated with a molten copper-based alloy infiltrant.

[0048] Blades may be separately attached or may be formed integrally with the blade portion. Use of separately attached blades may be desired due to different material requirements for each component, based on their structure, function, manufacturing details, expected loads, etc. For example, blades made of one type of steel may be separately attached to a blade portion formed of another type of steel, where the steel used to form the blades may be harder than the steel used to form the remaining blade portion. In another example, blades made of a matrix material may be separately attached to a blade portion formed of steel.

[0049] Blade portions may have cutter pockets formed along the cutting edge of each blade. For example, in embodiments having blades formed of a matrix material, cutter pockets may be formed in the blade during the molding process. In such embodiments, cutter displacements are positioned along the bottom of the mold (in the position eventually forming the cutting edge of each blade), and the matrix material is loaded in the mold and over the

displacements. Once the matrix material is formed into the blade portion shape through the molding process, the displacements may be removed to reveal the cutter pockets. In embodiments having blades formed of a steel material, cutter pockets may be machined into the cutting edge of each blade.

[0050] FIG. 1 shows an example of a blade portion of a multi-piece bit body according to embodiments of the present disclosure. The blade portion 1000 has a cutting face end 1001, a connection end 1002 opposite the cutting face end, and a gauge region 1003 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 1004 extends a depth into the blade portion from the cutting face end 1001. The cavity 1004 opens at the cutting face end 1001 of the blade portion and is proximate a central axis of the blade portion. According to embodiments of the present disclosure, a cavity may have two or more general shapes of volume. For example, a cavity may have a generally polygonal shaped volume at the cavity opening and a generally cylindrical shaped volume a distance away from the opening at the base of the cavity. Further, cavity 1004 may have a diameter at its opening ranging from  $1/5$  to  $2/3$  of the diameter of the blade portion 1000. Additionally, the depth of the cavity 1004 may range from 0.3 to 0.8 of the axial length of the blade portion. At least one blade 1005 protrudes from the blade portion and extends along the blade portion from adjacent to the cavity 1004 to the gauge region 1003 of the drill bit. A plurality of cutter pockets 1006 are formed along the cutting edge of each blade 1005.

[0051] Cutting elements may be brazed or otherwise attached to cutter pockets formed in blades of a blade portion according to embodiments of the present disclosure. For example, in some embodiments, blade cutting elements may be rotatably mounted to cutter pockets formed in the blades, such as by using a retention mechanism to hold the cutting element axially within the cutter pocket while still allowing the cutting element to rotate around its axis. Blade cutting elements may include an ultrahard cutting layer, such as a polycrystalline diamond (PCD) layer, thermally stable diamond layer, polycrystalline cubic boron nitride (PCBN) layer, or other superabrasive material layer, which is disposed on a substrate, such as a carbide substrate. The exposed top surface of the cutting layer may be referred to as a cutting face, i.e., the face of the cutting element that contacts and cuts a formation, and the edge formed by the intersection of the cutting face with the cutting layer side surface may be referred to as a cutting edge. Further, blade cutting elements may have planar and/or non-planar cutting faces. For example, in some embodiments, blade cutting elements may have a

pointed geometry, a conical shaped geometry, a dome shaped geometry, and/or a chisel shaped geometry. In some embodiments, the blade cutting elements may have a non-planar upper surface with an elevated crest extending substantially across the diameter of the cutting element (e.g., having a substantially hyperbolic paraboloid shape or substantially parabolic cylinder shape cutting face geometry). In some embodiments, blade cutting elements may have a planar cutting face. In some embodiments, a combination of blade cutting elements with planar and non-planar cutting faces may be used.

[0052] A threaded connection may be welded to the connection end of the blade portion (opposite the cutting face end of the blade portion), which may be used to attach the bit to a drill string or other tool used in drilling. According to embodiments of the present disclosure, a threaded connection may be welded to the connection end of a blade portion before a journal portion is assembled to the blade portion or after the journal portion is assembled to the blade portion. FIG. 2 shows an example of a blade portion made according to embodiments of the present disclosure. As shown, the blade portion 2000 has a cutting face end 2001, a connection end 2002 opposite the cutting face end, and a gauge region 2003 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 2004 extends a distance into the blade portion, and at least one blade 2005 protrudes from the blade portion and extends along the blade portion from adjacent to the cavity 2004 to the gauge region 2003 of the drill bit. The blade portion 2000 may be formed, for example, from a matrix material using a molding process, such as described above, or from steel, which may be machined to have desired dimensions and geometries. A plurality of blade cutting elements 2007 are attached to cutter pockets formed along the cutting edge of each blade 2005. Further, a threaded connection 2008 is welded to the connection end 2002 of the blade portion. According to some embodiments of the present disclosure, a threaded connection may be welded to a blade portion before attaching blade cutting elements to the blades in order to reduce the amount of excess heat exposure to the blade cutting elements.

[0053] Journal portions of a multi-piece bit body may be formed from a steel material. For example, according to some embodiments, a journal portion may be formed of steel having 0.15-0.35% carbon by weight, from 0.15-0.2% carbon by weight, or 0.25-0.35% carbon by weight. Further, steel used to form journal portions may be heat treated or case hardened. The type of steel used to form a journal portion may depend on, for example, the size and shape of the journal portion, the type of drilling environment the bit will be exposed to, and

the size and shape of the roller cones that will be mounted to each journal. According to some embodiments, a journal portion may be formed of 4715, 4815, 8620 or 8720 steel. The material used to form a journal portion may be the same or different as the material used to form a blade portion. According to embodiments of the present disclosure, journal portions may be machined into the desired shape, including a journal portion body and at least one journal protruding from the journal body. Further, upon machining the journal portion into the desired shape, the journal portion may be heat treated or case hardened, for example, by carburizing.

[0054] FIG. 3 shows an example of a journal portion 3000 having a journal portion body 3001 with a longitudinal axis 3005 extending there through, an attachment end 3002, and a journal end 3003 opposite from the attachment end 3002. The journal end 3003 has a generally polygonal shape, while the attachment end 3002 has a generally cylindrical shape. As used herein, a generally cylindrical shape may include a cylindrical shape having varying diameters. For example, as shown in FIG. 3, the generally cylindrical attachment end 3002 includes a larger diameter cylindrical portion, a smaller diameter cylindrical portion, and a plurality of grooves 3007 formed in the smaller diameter cylindrical portion (each groove 3007 having a relatively smaller diameter than the diameter of the smaller diameter cylindrical portion). In the embodiment shown, the transition between the journal end 3003 and the attachment end 3002 is the point along the journal portion length where the change in shape from cylindrical to polygonal occurs. According to some embodiments, a transition from the journal end to the attachment end of a journal portion may include a change in shape from a polygonal journal end to a cylindrical attachment end. In other embodiments, a transition from the journal end to the attachment end of a journal portion may include a reduced diameter. For example, a journal portion may have a polygonal shaped journal end and a polygonal shaped attachment end with a diameter smaller than the diameter of the journal end. In such embodiments, the transition between the journal end and attachment end may be defined as the point or segment along the length of the journal portion that is both axially lower than any journals extending from the journal portion and that has the reduction in diameter. Further, according to some embodiments, an attachment end of a journal portion may have a generally continuous shape, while a journal end of the journal portion may have a non-continuous shape. In such embodiments, the transition between the attachment end and the journal end may be defined as the point or segment along the length of the journal portion

that changes from the continuous shape to the non-continuous shape. For example, a journal portion may have an attachment end with a generally continuous cylindrical shape (e.g., a cylinder shape with one or more circumferential grooves), a journal end with a non-continuous shape, (e.g., a combination of different polygonal shapes), and a transition between the attachment end and the journal end at the point along the journal portion length where the continuous shape discontinues.

[0055] Referring still to FIG. 3, journals 3004 extend downward (i.e., extend in the direction away from the attachment end 3002) and radially outward from the longitudinal axis 3005 of the journal portion. As shown, the journal end 3003 has two journals 3004 extending therefrom. However, according to other embodiments of the present disclosure, a journal portion may have one journal extending from the journal end, three journals extending from the journal end, or more than three journals extending from the journal end. Such embodiments are illustrated in FIGS. 24-27 discussed below. Journals 3004 extend from sloped sidewalls, and as illustrated, at least one sidewall without a slope or with a lesser slope extends between the sloped sidewalls from which the journals 3004 extend. While FIG. 3 shows a non-sloped sidewall extending between either side of the sloped sidewall, it is also within the scope of the present disclosure that fewer or more non-sloped sidewalls may be used. As discussed below, as a ball passageway extends to such a surface, at least one sidewall without a journal may be incorporated for cone retention. In one or more embodiments, the angle of the sloped sidewalls with respect to a central axis of the journal portion 3000 may range from greater than 0 to less than 90 degrees.

[0056] The journal end 3003 of the journal portion has a locking segment 3006 formed at the base of the journal end, where the locking segment 3006 is formed from a plurality of intersecting outer side surfaces and located axially between the journals 3004 and the attachment end 3002. The locking segment 3006 shown has four intersecting outer side surfaces forming a square base (that will face and mate with the blade portion upon insertion of the journal portion into a cavity of blade portion), with the outer side surfaces extending axially away from the base. However, in other embodiments, a journal end may have a locking segment formed of three intersecting outer side surfaces to form a triangular base, or a journal end may have a locking segment formed of more than four intersecting outer side surfaces; that is, any polygonal base may be used. Upon inserting a journal portion into a cavity of a blade portion, a locking segment of the journal portion mates with corresponding

inner surfaces of the cavity, thereby locking the journal portion within the blade portion to inhibit the journal portion from rotating within the blade portion. For example, the journal portion 3000 shown in FIG. 3, having a square shaped locking segment 3006 formed at the journal end base, may be inserted into a mating cavity of a blade portion having a square cross-sectional shape. The journal portion 3000 further has a locking pin hole 3009 formed along its axial length, where the locking pin hole 3009 may receive a locking pin once assembled with a corresponding blade portion. Particularly, once a journal portion is inserted into a corresponding blade portion cavity, a locking pin may be inserted through the blade portion and into a locking pin hole formed within the journal portion, thereby locking the journal portion within the blade portion. Journal portions may have one or more locking pin holes formed along its length and/or around its perimeter. Further, a locking pin hole may be formed along the attachment end or along the journal end of a journal portion. For example, as shown in FIG. 3, a locking pin hole 3009 may be formed along the attachment end 3002 of the journal portion, adjacent to the journal end base. As illustrated, attachment end 3002 includes two segments of substantially cylindrical shapes, having two different radii. The substantially cylindrical segment adjacent the journal end 3003 may include the locking pin hole 3009 and may have a greater radius than the other segment axially spaced from the journal end 3003.

[0057] The attachment end 3002 of the journal portion 3000 has a plurality of grooves 3007 formed around its circumference and along the axial length of the attachment end. During the process of assembling the journal portion to a blade portion, an o-ring (not shown) may be disposed within each groove 3007 formed around the attachment end 3002. O-rings may be formed of various types of sealing materials depending on, for example, the size of the o-ring, the squeeze between the journal portion and blade portion (e.g., the size of the space formed between the groove and the blade portion cavity), and the amount of pressure. For example, according to some embodiments, an o-ring may be formed of nitrile, highly saturated nitrile (“HSN”), or other types of nitrile butadiene rubber (“NBR”), or combinations thereof. Further, the size of an o-ring (e.g., the diameter and/or thickness of the o-ring) may be selected depending on, for example, the amount of stretch the material can withstand before failure, the size of the space formed between the groove and the blade portion cavity, and the pressure exerted on the o-ring.

[0058] The areas defined between adjacent grooves 3007 may be referred to herein as lubrication sections. A lubrication hole 3008 may be formed within each lubrication section, which may extend through the body of the journal portion 3000 to provide lubricant from the lubrication hole 3008 to a retention system formed at the journals (and discussed more below). According to embodiments of the present disclosure, prior to inserting a journal portion into a cavity of a blade portion, at least one o-ring may be disposed around the attachment end of the journal portion, where each o-ring defines a lubrication section. Upon assembly, lubricant may be provided from a lubricant reservoir in a blade portion to a lubrication section formed around the attachment end of the corresponding journal portion, which may then flow through a lubrication hole and within the journal portion body. The journal portion 3000 shown in FIG. 3 has two lubrication sections formed between three grooves 3007. However, in some embodiments, a journal portion may have one lubrication section formed between two adjacent o-rings, or a journal portion may have more than two lubrication sections formed between adjacent o-rings.

[0059] Referring now to FIGS. 24 and 25, an embodiment of a journal portion having three journals (and roller cones) is shown. FIGS. 24 and 25 shows an example of a journal portion 3000 having a journal portion body 3001 with a longitudinal axis 3005 extending there through, an attachment end 3002, and a journal end 3003 opposite from the attachment end 3002. The journal end 3003 has a generally polygonal shape, and in this illustrated embodiment, a hexagonal cross-sectional. Three journals 3004 extend downward (i.e., extend in the direction away from the attachment end 3002) and radially outward from the longitudinal axis 3005 of the journal portion, and as illustrated in FIG. 25, may have roller cones 3050 mounted and assembled thereon. The attachment end 3002 includes a plurality of grooves 3007 formed around its circumference and along the axial length of the attachment end, and as illustrated in FIG. 25, a plurality of o-rings 3040 may fit within the plurality of grooves 3007.

[0060] Referring now to FIGS. 26 and 27, an embodiment of a journal portion having a single journal (and roller cone) is shown. FIGS. 24 and 25 shows an example of a journal portion 3000 having a journal portion body 3001 with a longitudinal axis 3005 extending there through, an attachment end 3002, and a journal end 3003 opposite from the attachment end 3002. The journal end 3003 has a generally cylindrical shape, having an angled slice cut therethrough. A single journal 3004 extends downward (i.e., extend in the direction away



from the attachment end 3002) and radially toward the longitudinal axis 3005 of the journal portion from the angled surface of the journal portion, and, as illustrated in FIG. 27, may have a roller cone 3050 mounted and assembled thereon. The attachment end 3002 includes a plurality of grooves 3007 formed around its circumference and along the axial length of the attachment end, and as illustrated in FIG. 27, a plurality of o-rings 3040 may fit within the plurality of grooves 3007.

[0061] Referring now to FIGS. 4 and 5, an assembly of roller cones to a journal portion is shown. Particularly, FIG. 4 shows a journal portion 4000 having a journal portion body 4001 with a longitudinal axis 4005 extending there through, an attachment end 4002, and a journal end 4003 opposite from the attachment end 4002. Journals 4004 extend in the direction away from the attachment end 4002 and radially outward from the longitudinal axis 4005 of the journal portion. Each journal 4004 extends from a journal surface 4012 of the journal end 4003, and a transition surface 4013 extends between the journal surfaces 4012. Journal surfaces 4012 are sloped with respect to the journal longitudinal axis 4005, while transition surfaces 4013 are non-sloped with respect to the journal longitudinal axis 4005 (the transition surfaces 4013 are parallel with the journal longitudinal axis 4005). However, according to embodiments of the present disclosure, transition surfaces may be sloped or non-sloped. Further, a journal end may include one or more transition surfaces and one or more journal surfaces.

[0062] As shown, the journal end 4003 of the journal portion has a square-shaped locking segment 4006 formed at the base of the journal end. The locking segment 4006 is formed by four intersecting outer side surfaces and located axially between the journals 4004 and the attachment end 4002. The attachment end 4002 of the journal portion 4000 has a plurality of grooves formed around its circumference and along the axial length of the attachment end. An o-ring 4007 is disposed within each groove. The area between adjacent o-rings 4007, which may be referred to as a lubrication section, has a lubrication hole 4008 opening formed therein, and a lubrication hole 4008 may be present in each lubrication section. A lubrication channel 4011 extends from the lubrication hole 4008 formed in each lubrication section, through the body of the journal portion 4000, and to a retention system formed at the journal end 4003. As shown, the retention system includes a ball passageway 4009 extending from an opening formed at the journal end 4003 to a journal race 4010, where the lubrication hole 4008 intersects with the ball passageway 4009. Particularly, ball passageway 4009 extends

from an opening formed at a transition surface 4013 of the journal end. In other embodiments, a ball passageway may extend from one journal surface to a journal extending from a second journal surface, depending on the size and configurations of the journal surfaces and the size of the journals, for example.

[0063] Roller cones 4015 may be retained to the journals 4004 by fitting a plurality of retention balls into a ball race formed between the journal race 4010 and a corresponding roller cone race. Particularly, the retention balls may be inserted through the ball passageway 4009 to the ball race formed between each journal 4004 and roller cone 4015, where each ball passageway 4009 extends through the journal end 4003 to each journal race 4010. For example, in some embodiments, a roller cone 4015 may first be fitted on a journal 4004, and then a plurality of retention balls may be inserted through a ball passageway 4009 to fit in the ball race formed between the journal race 4010 and corresponding roller cone race. Retention balls may be retained in the ball races by a ball retainer (not shown), which may be inserted into the ball passageway 4009 after the retention balls, and then secured in place (such as by a plug welded in place). The retention balls may carry any thrust loads tending to remove the roller cone 4015 from the journal 4004 and thereby retain the roller cone on the journal. Further, lubricant provided through the lubrication hole 4008 may flow to the ball passageway 4009 and into the ball race to provide lubrication to the retention balls.

[0064] The direction of the ball passageway 4009 extension through the journal end to the journal race 4010 may be defined by a BHP breakout angle, a BHP 45 angle, and a BHP twist angle. The BHP breakout angle, BHP 45 angle and BHP twist angles may be defined with respect to a journal longitudinal axis and a journal portion longitudinal axis. Referring to FIG. 21, a BHP breakout angle refers to the angle  $\alpha$  formed between the ball passageway 1609 and the z-axis when viewed along the Y-Z plane. According to some embodiments, a ball passageway may have a BHP breakout angle ranging from about 0 degrees to about 45 degrees, and in some embodiments, the BHP breakout angle may range from about 20 degrees to about 30 degrees. Referring now to FIG. 22, the BHP 45 angle refers to the angle  $\beta$  formed between the ball passageway 1609 and the y-axis when viewed along the X-Y plane. According to some embodiments, a ball passageway may have a BHP 45 angle ranging from about 0 degrees to about 45 degrees, and in some embodiments, the BHP breakout angle may range from about 20 degrees to about 30 degrees. Referring now to FIG. 23, the BHP twist angle refers to the angle of rotation  $\gamma$  around the journal longitudinal axis

formed between the ball passageway 1609 and the x-axis when viewed along the X-Z plane. According to some embodiments, a ball passageway may have a BHP twist angle ranging from about 0 degrees to about 45 degrees, and in some embodiments, the BHP breakout angle may range from about 20 degrees to about 30 degrees.

[0065] Roller cones may include bodies having a rounded, a conical, or a disc shape and a plurality of cutting elements disposed thereon. For example, as shown in FIG. 5, a roller cone 4015 has a frustoconical shaped body with a plurality of cutting elements 4016 disposed thereon. Roller cone sizes may differ with respect to one or more of a roller cone's outer radius, nose projection, radius of curvature, etc. As shown, the roller cone 4015 has at least four circumferential rows of cutting elements 4016. However, other embodiments may have more or less than four rows of cutting elements. Further, roller cones may have cutting elements disposed thereon in arrangements other than in rows.

[0066] Roller cones may have various types of roller cone cutting elements disposed thereon. For example, in some embodiments, roller cone cutting elements may be formed integrally with the roller cone (and formed of the same base material of the roller cone), which may be referred to as milled teeth. In other embodiments, roller cone cutting elements may be press fitted (interference fitted) or otherwise attached within holes formed around the roller cones. Roller cone cutting elements may be formed of, for example, carbide materials, such as tungsten carbide, natural or synthetic diamond, boron nitride, or any one or combination of hard or superhard materials. For example, roller cone cutting elements may include tungsten carbide inserts, diamond enhanced inserts, or PCBN inserts.

[0067] Referring now to FIG. 6, assembly of a journal portion 6000 to a blade portion 6050 is shown. The journal portion 6000 has a journal portion body 6001 with an attachment end 6002 and a journal end 6003 opposite from the attachment end 6002. Attachment end 6002 has a generally cylindrical shape, while the journal end 6003 has a generally polygonal shape. Journals (not shown) extend in the direction away from the attachment end 6002 and radially outward from the journal end 6003, and a roller cone 6015 is rotatably mounted to each journal. A plurality of roller cone cutting elements 6016 are attached to the roller cones 6015. The attachment end 6002 of the journal portion 6000 has a plurality of o-rings 6007 disposed within grooves formed along the axial length of the attachment end 6002. Lubrication sections formed between adjacent o-rings 6007 each have a lubrication hole 6008

opening formed therein. A lubrication channel extends from the lubrication hole 6008, through the body of the journal portion 6000, to a retention system formed at the journal end 6003 to retain a roller cone 6015 to a journal. For example, the retention system may include a ball passageway extending from an opening formed at the journal end to a ball race formed between a journal race and a corresponding roller cone race, where the lubrication hole intersects with the ball passageway. A plurality of retention balls may be inserted through the ball passageway and into the ball race to retain the roller cone to the journal.

[0068] According to some embodiments of the present disclosure, a journal portion may have a number of lubrication sections, each with a lubrication hole formed therein, equal to the number of roller cones mounted thereto. For example, in some embodiments, a journal portion having two roller cones, each mounted to a journal extending from the journal end, may have two lubrication sections defined between three o-rings, where each lubrication section has a lubrication hole to provide lubrication to each of the two retention systems used to retain the roller cones to the journals. In other embodiments, a journal portion may have a number of lubrication sections different from the number of roller cones mounted thereto. For example, more than one lubrication hole may be formed in a lubrication section, where each lubrication hole provides lubrication to separate retention systems used to retain roller cones to journals.

[0069] The blade portion 6050 has a cutting face end 6051, a connection end 6052 opposite the cutting face end, and a gauge region 6053 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 6054 extends a distance into the blade portion, and at least one blade 6055 protrudes from the blade portion and extends along the blade portion from adjacent to the cavity 6054 to the gauge region 6053 of the drill bit. The at least one blade 6055 may extend radially and axially along the blade portion from a first end to a second end, where the first end is at a radial distance from the cavity 6054, the distance ranging from 0 to 20% of the bit diameter, and the second end is at the gauge region 6053 of the drill bit. Further, the cutting face end 6051 may be designed to accommodate roller cones 6015 mounted to the journal portion 6000 once the journal portion 6000 is assembled with the blade portion 6050. For example, the size, number and position of the blades 6055 may be designed to provide enough space for the roller cones 6015 to extend a radial distance across the cutting face end 6051 of the blade portion 6050. A plurality of

blade cutting elements 6057 are attached to cutter pockets formed along the cutting edge of each blade 6055.

[0070] The blade portion 6050 has at least one lubrication reservoir 6056, where a passage (not shown) extends through the blade portion, from the lubrication reservoir 6056 to the cavity 6054. Upon attaching the journal portion 6000 to the blade portion 6050, each passage opens to one of the lubrication sections formed along the attachment end 6002 of the journal portion 6000, thereby providing a passage for lubrication to flow from each lubrication reservoir to a lubrication hole 6008 formed in each lubrication section, which may then flow through the lubrication holes 6008 to the retention systems used to retain the roller cones 6015 to journals. In other words, according to embodiments of the present disclosure, a journal portion may fit within a cavity of a blade portion, such that one or more passages extending from a lubrication reservoir align with lubrication sections formed around the attachment end of the journal portion. In some embodiments, the journal portion may be aligned within a blade portion using the mating shapes of a locking segment formed around the journal portion and the cavity formed in the blade portion.

[0071] According to embodiments of the present disclosure, a journal portion may include a locking segment formed by a plurality of intersecting outer side surfaces, and upon inserting the journal portion into a cavity formed in a blade portion, the locking segment mates with a plurality of inner surfaces of the cavity. For example, as shown in FIG. 6, the journal end 6003 of the journal portion has a square-shaped locking segment 6006 formed at the base of the journal end. The locking segment 6006 is formed by four intersecting outer side surfaces and located axially between the roller cones 6015 and the attachment end 6002. The cavity 6054 formed in the blade portion 6050 has four intersecting inner surfaces 6059 defining a locking segment receiving volume. The locking segment receiving volume corresponds in size and shape to the locking segment 6006 of the journal portion 6000. Thus, when the journal portion 6000 is assembled with the blade portion 6050, the locking segment 6006 of the journal portion 6000 mates with the corresponding inner surfaces 6059 of the cavity 6054 formed in the blade portion 6050. The embodiment shown in FIG. 6 has a locking segment 6006 formed of four intersecting outer side surfaces and a cavity 6054 with four mating intersecting inner surfaces 6059. However, other embodiments may have a locking segment formed of more or less than four intersecting outer side surfaces and a cavity with corresponding intersecting inner surfaces. By forming a locking segment and corresponding

portion of a cavity with intersecting, or angled, side surfaces, the locking segment may be rotationally locked within the cavity. In other words, the angles formed by the intersecting side surfaces in the corresponding shapes of the locking segment and cavity may prevent the locking segment, and thus the journal portion, from rotating within the blade portion cavity.

[0072] Cavity 6054 further includes an attachment end receiving volume 6060 defined by one or more inner surfaces located a distance from the cavity opening and at a greater depth than the locking segment receiving volume. As shown, the attachment end receiving volume 6060 has a generally cylindrical shape, defined by cylindrical inner surfaces with multiple radii corresponding with varying radii of the attachment end 6002 of the journal portion 6000. According to embodiments of the present disclosure, a cavity may include two or more volumes having different shapes or sizes that correspond with the locking segment and attachment end of a journal portion.

[0073] Further, FIG. 6 shows locking pins 6009 inserted into locking pin holes formed along the journal body 6001, which may be used to lock the journal portion 6000 to the blade portion 6050. The locking pins are shown in FIG. 6 as being disposed in the locking pin holes prior to the journal portion being inserted into the blade portion 6050 cavity 6054 in order to show configuration of locking pins 6009 with respect to the journal portion 6000. However, according to embodiments of the present disclosure, the locking pins 6009 are inserted into locking pin holes formed in the journal portion 6000 after inserting the journal portion 6000 into the blade portion 6050. Particularly, the journal portion 6000 may be inserted into the cavity 6054 of the blade portion 6050 such that blade locking pin holes 6058 align with the locking pin holes formed in the journal portion 6000. The locking pins 6009 may then be inserted through the blade locking pin holes 6058 and into the locking pin holes formed in the journal portion 6000, such that the locking pins 6009 extend through the blade portion 6050 and at least partially into the journal portion body 6001. Locking pins 6009 may have a length equal to the combined length of a blade locking pin hole 6058 and corresponding journal portion locking pin hole. Further, a locking pin hole formed in the journal portion may extend from 1/8 of the diameter of the journal portion to the entire diameter of the journal portion. For example, in embodiments having a journal portion locking pin hole that extends the entire diameter of journal portion, a locking pin may have a length equal to or greater than the combined length of a blade portion locking pin hole and the diameter of the

journal portion, such that the locking pin may be inserted through the blade portion locking pin hole and through the entire diameter of the journal portion.

[0074] FIG. 7 shows a journal portion 7000 assembled with a blade portion 7050 according to embodiments of the present disclosure. The journal portion 7000 has an attachment end (not shown) and a journal end opposite from the attachment end, where roller cones 7015 are rotatably mounted to journals extending from the journal end. A plurality of roller cone cutting elements 7016 are attached to the roller cones 7015. The blade portion 7050 has a cutting face end 7051, a connection end 7052 opposite the cutting face end, and a gauge region 7053 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity (not shown) extends a distance into the blade portion, where a portion of the journal portion 7000 is inserted into the cavity. At least one blade 7055 protrudes from the blade portion 7050 and extends along the blade portion from adjacent to the journal portion 7000 to the gauge region 7053 of the drill bit. According to embodiments of the present disclosure, at least one blade 7055 may extend radially and axially along the blade portion 7050 from a first end to a second end, where the first end is at a radial distance from the journal portion ranging from 0 to 20% of the bit diameter and the second end is at the gauge region 7053 of the drill bit. A plurality of blade cutting elements 7057 are attached to cutter pockets formed along the cutting edge of each blade 7055.

[0075] The blade portion 7050 has at least one lubrication reservoir 7056, where a passage (not shown) extends through the blade portion, from the lubrication reservoir 7056 to the inserted part of the journal portion 7000 in order to provide lubrication to the retention systems used to retain the roller cones 7015 to the journals, such as described above. Further, locking pins 7009 are inserted through blade locking pin holes 7058 formed in the blade portion 7050 and into corresponding locking pin holes formed in the journal portion 7000. Particularly, the journal portion 7000 may be inserted into the cavity of the blade portion 7050 such that blade locking pin holes 7058 align with the locking pin holes formed in the journal portion 7000. The locking pins 7009 may then be inserted through the blade locking pin holes 7058 and into the locking pin holes formed in the journal portion 7000, such that the locking pins 7009 extend through the blade portion 7050 and at least partially into the journal portion. The locking pins 7009 may be secured within the blade locking pin holes 7058 by welding the exposed portion of the locking pins 7009 to the outer surface of the blade portion 7050, such

as by spot welding, friction stir welding, or other conventional welding methods known in the art.

[0076] FIG. 8 shows a diagram of a journal portion 8000 assembled to a blade portion 8050 according to embodiments of the present disclosure. The journal portion 8000 has an attachment end 8002 and a journal end 8003 opposite from the attachment end 8002. Journals 8004 extend downward and radially outward from the journal end 8003, and a roller cone 8015 is rotatably mounted to each journal. A plurality of roller cone cutting elements 8016 are attached to the roller cones 8015. The attachment end 8002 of the journal portion 8000 has a plurality of o-rings 8007 disposed within grooves formed along the axial length of the attachment end 8002. Lubrication sections formed between adjacent o-rings 8007 each have a lubrication channel 8008 extending from a lubrication hole formed in the attachment end 8002, through the body of the journal portion 8000, to a retention system formed at the journal end 8003 to retain a roller cone 8015 to a journal 8004. The retention system includes a ball passageway 8011 extending from an opening formed at the journal end 8003 to a ball race formed between a journal race 8012 and a corresponding roller cone race, where the lubrication channel 8008 intersects with the ball passageway 8011. A plurality of retention balls may be inserted through the ball passageway 8011 and into the ball race to retain the roller cone 8015 to the journal 8004.

[0077] The blade portion 8050 has a cutting face end 8051, a connection end 8052 opposite the cutting face end, and a gauge region 8053 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 8054 extends a distance into the blade portion, where a portion of the journal portion 8000 is inserted into the cavity. The blade portion 8050 has at least one lubrication reservoir 8056, and a passage 8057 extends through the blade portion, from the lubrication reservoir 8056 to the inserted part of the journal portion 8000. The journal portion 8000 is inserted into the cavity 8054 such that the passage 8057 aligns with the hole to the lubrication passageway 8008, thereby providing lubrication from the lubrication reservoir 8056 in the blade portion 8050 to the retention systems in the journal portion 8000 used to retain the roller cones 8015 to the journals 8004.

[0078] Locking pins 8009 are inserted through blade locking pin holes formed in the blade portion 8050 (e.g., between blades) and into corresponding locking pin holes formed in the journal portion 8000. Particularly, the journal portion 8000 may be inserted into the cavity of



the blade portion 8050 such that blade locking pin holes align with the locking pin holes formed in the journal portion 8000. The locking pins 8009 may then be inserted through the blade locking pin holes and into the locking pin holes formed in the journal portion 8000, such that the locking pins 8009 extend through the blade portion 8050 and at least partially into the journal portion 8000.

[0079] According to embodiments of the present disclosure, a method of manufacturing a hybrid drill bit may include determining a primary torque transfer area between a journal portion and a blade portion of a multi-piece bit body and obtaining or forming the journal portion and the blade portion. The journal portion may be formed, such as by machining, to have an attachment end, a journal end opposite from the attachment end, at least one journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion, and a locking segment formed of a plurality of intersecting outer side surfaces around the journal portion between the attachment end and the journal end, where a total outer side surface area of the locking segment is equal to (e.g., approximately equal to) the primary torque transfer area. The blade portion may be formed, such as with a molding process and/or by machining, to have a cavity extending a distance into the blade portion and at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit. Upon forming the journal portion and the blade portion, the attachment end of the journal portion may be inserted into the cavity of the blade portion to form the multi-piece bit body.

[0080] FIG. 9 shows a disassembled multi-piece bit body according to embodiments of the present disclosure. The journal portion 9000 has an attachment end 9002, a journal end 9003 opposite from the attachment end, at least one journal (not shown) extending from the journal portion, on which roller cones 9015 are rotatably mounted, and a locking segment 9006 formed of a plurality of intersecting outer side surfaces 9007 around the journal portion between the attachment end and the journal end. A total outer side surface area of the locking segment is equal to or greater than a predetermined primary torque transfer area. The blade portion 9050 has a cutting face end 9051, a connection end 9052 opposite the cutting face end, and a gauge region 9053 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 9054 extends a distance into the blade portion, and at least one blade 9055 extends along the blade portion from adjacent to the cavity 9054 to a gauge region 9053 of the drill bit. The cavity 9054 has a plurality of intersecting inner

surfaces 9059 that correspond to the shape of the intersecting outer side surfaces 9007 of the journal portion locking segment 9006.

[0081] Upon assembling the journal portion 9000 to the blade portion 9054, various torque forces may be exerted between the journal portion and the blade portion during rotation and contact with other surfaces (e.g., during drilling a formation). For example, different rotational forces may be experienced by a blade portion and a journal portion of a multi-piece bit body during drilling. As one portion experiences higher rotational forces, that portion may apply torque to the other portion, causing coinciding rotation of the different portions of the multi-piece bit body. According to embodiments of the present disclosure, corresponding rotation between different portions of a multi-piece bit body may be achieved using interlocking shapes between the different portions, where selected torque forces between the interlocking portions may be calculated prior to manufacturing or obtaining the multi-piece bit body. Calculating torque parameters prior to manufacturing or obtaining a multi-piece bit body may allow a manufacturer to design the interlocking shapes and surfaces of the different multi-piece bit body portions based on predicted torque forces. For example, according to embodiments of the present disclosure, torque forces may be predicted for a multi-piece bit body formed of components (e.g., blade portions, journal portions and locking pins) having a selected shape and size, where predicting may be performed using simulations of the multi-piece bit body and/or using calculations of certain torque forces experienced between the selected components. Based on the predicted torque forces, a bit manufacturer may then alter or re-design the multi-piece bit body to improve bit performance, for example, by altering the shape or size of one or more multi-piece bit components or by using a different material to form one or more of the components. The steps of predicting and altering may be performed more than once.

[0082] Referring still to FIG. 9, a primary torque transfer force may be calculated based on a primary torque plane formed between the mating intersecting outer side surfaces 9007 of the journal portion locking segment 9006 and the intersecting inner surfaces 9059 of the cavity 9054. The primary torque plane has a total torque transfer contact area equal to the total surface area of the intersecting outer side surfaces 9007 of the journal portion locking segment 9006. In other words, the total torque transfer contact area of the locking segment 9006 is equal to the sum of the surface area of each of the four intersecting outer side surfaces 9007. In embodiments having a locking segment formed of three intersecting outer

side surfaces, the total torque transfer contact area is equal to the total surface area of the three outer side surfaces. Embodiments having a locking segment formed of five intersecting outer side surfaces have a total torque transfer contact area equal to the total surface area of the five outer side surfaces; embodiments having a locking segment formed of six intersecting outer side surfaces have a total torque transfer contact area equal to the total surface area of the six outer side surfaces; and so forth. According to some embodiments of the present disclosure, a locking segment 9006 may have a total torque transfer contact area ranging from greater than 1 sq.in. (645.2 sq.mm), greater than 2 sq.in. (1290.3 sq.mm), greater than 4 sq.in. (2580.6 sq.mm), greater than 6 sq.in. (3871 sq.mm), greater than 8 sq.in. (5161.3 sq.mm), or between 1 sq.in. (645.2 sq.mm) and 10 sq.in. (6451.6 sq.mm) in other embodiments, however, any suitable total torque transfer contact area may be used. Further, according to embodiments of the present disclosure, a total torque transfer contact area may be selected based on torque transfer forces calculated for a multi-piece bit body. The multi-piece bit body may then be formed by machining the size and the shape of a locking segment to have intersecting outer side surfaces with a sum surface area equal to the total torque transfer contact area.

[0083] Referring now to FIG. 10, a secondary torque transfer force may be calculated based on a lock pin torque capacity. As used herein, a lock pin torque capacity refers to the maximum torque that can be applied to a locking pin on a continual basis and still maintain a normally expected fatigue life. As shown in FIG. 10, a journal portion 1100 may have an attachment end 1102, a journal end 1103 opposite from the attachment end, at least one journal (not shown) extending from the journal portion, on which roller cones 1105 are rotatably mounted, and a locking segment 1107 formed of a plurality of intersecting outer side surfaces around the journal portion between the attachment end and the journal end. Two locking pins 1109 are inserted into locking pin holes formed in the attachment end 1102 of the journal portion, proximate the locking segment 1107. However, other embodiments may have one locking pin or more than two locking pins. The lock pin torque capacity of each locking pin 1109 may be calculated using the cross sectional area of the locking pin 1109, the torque section radius, and the material yield strength of the material forming the locking pin 1109. For example, a material yield strength of a locking pin 1109 formed of 4815 steel may be about 124 ksi. However, other embodiments may include locking pins formed of other types of steel. The torque capacity of a locking pin may be calculated using the equation:

(torque section radius)x(cross sectional area of the locking pin)x(material yield strength)/2. In one or more embodiments, the torque capacity may range from 0.5 kft.lb (677.9 Nm) to 10 kft.lb (13560 Nm), with a cross-sectional area ranging from 0.1 sq.in (645.2 sq.mm) to 0.8 sq.in (5161.3 sq.mm), and a radius of  $\frac{1}{4}$  to  $\frac{2}{3}$  the bit radius.

[0084] Further, according to embodiments of the present disclosure, weight on bit (“WOB”) forces may be exerted between a journal portion and a blade portion of a multi-piece bit body during drilling. For example, a primary weight on bit force may be calculated based on a weight on bit transfer plane formed between a journal portion and a blade portion of a multi-piece bit body. Calculating weight on bit forces of a multi-piece bit body design prior to manufacturing the multi-piece bit body may allow a manufacturer to re-design or alter the design of the multi-piece bit body components in order to optimize performance of the multi-piece bit body. According to embodiments of the present disclosure, weight on bit forces may be predicted for a multi-piece bit body, such as by simulating performance of the multi-piece bit body and/or by calculating certain forces experienced between selected components of the multi-piece bit body. Based on the predicted weight on bit forces, a bit manufacturer may then alter or re-design the multi-piece bit body to improve bit performance, for example, by altering the shape or size of one or more multi-piece bit components or by using a different material to form one or more of the components. The steps of predicting and altering may be performed more than once.

[0085] For example, referring now to FIG. 11, a primary weight on bit transfer force may be predicted between a journal portion 1110 and a blade portion 1150 of a multi-piece bit body. The journal portion 1110 has an attachment end 1112, a journal end 1113 opposite from the attachment end, at least one journal (not shown) extending from the journal portion, on which roller cones 1115 are rotatably mounted, and a locking segment 1116 formed of a plurality of intersecting outer side surfaces around the journal portion between the attachment end and the journal end. The locking segment 1116 has a base surface 1117, where the base surface 1117 intersects each of the outer side surfaces at an edge. The blade portion 1150 has a cutting face end 1151, a connection end 1152 opposite the cutting face end, and a gauge region 1153 defining an outer diameter of the bit, between the cutting face end and the connection end. A cavity 1154 extends a distance into the blade portion, and at least one blade 1155 extends along the blade portion from adjacent to the cavity 1154 to a gauge region 1153 of the drill bit. The cavity 1154 has a plurality of intersecting inner surfaces that

correspond to the shape of the intersecting outer side surfaces of the journal portion locking segment 1116 and a support surface 1159 that corresponds to the shape of the base surface 1117 of the locking segment 1116. Thus, upon assembling the journal portion 1110 to the blade portion 1150, the intersecting inner surfaces and support surface 1159 of cavity 1154 receives and mates with the locking segment 1116 of the journal portion 1110. A weight on bit transfer plane is formed between the base surface 1117 and support surface 1159. The weight on bit transfer capacity between the journal portion 1110 and blade portion 1150 may be calculated using the contact area of the weight on bit transfer plane (i.e., the area of contact between the base surface 1117 and the support surface 1159) and the material yield strength of the material forming the journal portion 1110. For example, a material yield strength of a journal portion 1110 formed of 4130 steel may be about 52 ksi. However, other embodiments may include journal portions formed of other types of steel. The WOB transfer capacity may be calculated using the equation: (contact area)x(material yield strength). According to embodiments of the present disclosure, a weight on bit transfer capacity may range from greater than 100 klb, greater than 120 klb, greater than 150 klb, or 100 klb to 180 klb in other embodiments. The actual weight on bit transfer when a hybrid bit is being used may be greater than 30 klb for bit size less than 12.25" and greater than 50 klb for bit size larger than 12.25".

[0086] According to embodiments of the present disclosure, a WOB transfer plane contact area may be selected based on a predicted primary WOB transfer force calculated for a multi-piece bit body. For example, a design of a journal portion and corresponding blade portion may have a WOB transfer plane contact area formed between the mating base surface and support surface of the journal portion locking segment and blade cavity. The primary WOB transfer force for the design may be calculated based on the selected WOB transfer plane contact area and material of the components. A bit designer may then alter or redesign the journal portion and/or blade portion based on the predicted primary WOB transfer force to improve bit performance. For example, the size of the base surface and/or support surface may be altered and/or the type of material used to form the journal portion and/or blade portion may be altered, thereby changing the predicted primary WOB transfer force between the journal portion and blade portion. The steps of predicting and altering may be performed once or more than once.

[0087] Further, according to embodiments of the present disclosure, multi-piece bit body components may be designed such that the assembled multi-piece bit body has radially and/or axially displaced roller cone and blade cutting profiles. By radially displacing a blade cutting profile from a roller cone cutting profile in a hybrid drill bit according to embodiments of the present disclosure, high inner cutting efficiency may be provided by the high shear feature of the outwardly facing roller cones, increased steerability may be provided with some rotating cutting elements contacting the wall of the wellbore, and a wider range of formation drilling may be achieved.

#### EXAMPLES

[0088] An example of a hybrid drill bit formed using methods of the present disclosure is shown in FIGS. 12 and 13, which show a top view and a side view, respectively, of a hybrid drill bit 100. The bit 100 has a multi-piece bit body 110 with a longitudinal axis 112 extending axially there through. The bit 100 has a bit cutting face 102, a gauge region 138, and a threaded pin end 104 opposite from the bit cutting face 102. The bit cutting face 102 refers to the side of the bit substantially facing in the direction of drilling, and that may engage the bottom hole of the wellbore being drilled. A drill string or other drilling tools may be attached to the threaded pin end 104 of the bit, for example, to rotate the bit 100. The gauge region 138 of the bit may cut or maintain the gauge, or outer diameter, of the borehole being drilled, and thus may engage a sidewall of the wellbore. Bit 100 includes a plurality of roller cones 120 and a plurality of blades 130 (though other embodiments may include one or more roller cones and/or one or more blades) arranged in such a manner that the roller cones 120 engage with and cut a bottom hole, but do not engage with the sidewall of a wellbore, and blades 130 at least engage and cut the sidewall of the wellbore. However, it is also within the scope of the present disclosure that the blades 130 may extend through the gauge region 138 and into the bit cutting face 102 (thus forming a part of the bit cutting face). Because roller cones 120 engage with and cut a bottom hole (and not a side wall), the outer radial extent of the roller cones 120 is radially inside of the bit diameter, defined by the gauge 138. The extent of overlap between cutting elements on roller cone 120 and blade 130 depends on the blade 130 location, relative to roller cones 120. For example, blades 130.1 (illustrated as being at offset from roller cones 120) extend to a more radially interior position than blades 130.2 (illustrated as being radially in line with roller cones 120, *i.e.*, a radial plane of the blade overlaps roller cone). As used herein, the terms “upper”, “uppermost” or “above” refer

to the direction facing toward the threaded pin end 104 of the bit 100 and the terms “lower”, “lowest” or “below” refer to the direction facing toward the axial end of the bit having journals extending therefrom.

[0089] The roller cones 120 are each rotatably mounted to a journal (not shown) extending from the multi-piece bit body 110 at the bit cutting face 102. At least one blade 130 protrudes from the bit body 110 and extends radially and axially along the bit body 110 from a first end 132 to a second end 134 (illustrated as ending at a heel surface, as that term is known in the art). As shown, the first end 132 of the blade 130.2 is positioned along the bit cutting face 102, at a radial distance 136 farther from the longitudinal axis 112 than the radially outermost portion of at least one roller cone 120 (and thus farther than the journal that the roller cone is mounted to). Depending on the size and shape of the bit cutting face 102, the blades 130 may extend a radial distance along the bit cutting face 102 as well as an axial distance from the bit cutting face 102 along a gauge region 138 of the bit 100, where the second end 134 of the blades 130 are at the gauge region 138. Further, at least one of the first ends 132 of the blades 130 and at least one of the plurality of journals may be positioned within a shared radial plane 140 (i.e., a plane intersecting the longitudinal axis 112 at a perpendicular angle), such that the axial height of the first end 132 and the axial height of the journal overlap. In other words, the radial plane 140 may intersect both the first end 132 of a blade 130 and the journal. In other embodiments, the difference in axial height between at least one journal and at least one blade first end may be large enough that no radial plane may be shared between the at least one journal and blade first end.

[0090] Referring now to FIG. 14, a top view of a hybrid drill bit 300 having a journal portion assembled with a blade portion, according to embodiments of the present disclosure, is shown. The bit has a plurality of journals 320 extending from a multi-piece bit body 310 (the journal portion assembled to the blade portion), where each journal 320 has a journal axis 322 extending from a base of the journal 320 through the length of the journal 320. As used herein, a base of a journal may be drawn along a plane intersecting the journal where it meets the multi-piece bit body. The journals 320 are positioned at the bit cutting face such that each of the journal axes 322 are at a first radial distance 325 (at the intersection of the journal axis 322 with the journal portion of the multi-piece bit body 310) from the longitudinal axis 312 of the bit 300. As used herein, the term “first radial distance” refers to the radial distance measured between the longitudinal axis of a bit and the journal axis of a journal at its base.

As shown, the bit 300 has three journals 320 with journal axes 322 at the same first radial distance 325. However, a hybrid drill bit may have more or less than three journals, as well as non-equal first radial distances. For example, in embodiments having more than one journal, each axis of the journals may be at an equal radial distance from the bit longitudinal axis, or each axis of the journals may be at different radial distances from the bit longitudinal axis. A first radial distance may range from a lower limit of 0, greater than 0,  $1/32$ ,  $1/16$ ,  $1/8$  or  $1/4$  of the bit radius to an upper limit of  $1/8$ ,  $1/4$ ,  $1/3$ , or  $1/2$  of the bit radius, where any lower limit may be combined with any upper limit.

[0091] Additionally, a plurality of blades 330 extend radially from the blade portion of the multi-piece bit body 310. Each of the blades 330 extends axially along the body 310 from a first end 332 (positioned at the bit cutting face such that the cutting elements thereon may cut and engage a wellbore bottom hole) to a second end 334 (at a gauge region of the bit such that the cutting elements thereof may cut and engage a side wall of the wellbore). Further, blades 330 may have a top face 337 (which faces radially outward from the multi-piece bit body), a leading face 336 (which faces in the direction of bit rotation), and a trailing face 338 opposite from the leading face 336. The first end 332 of a blade 330 may be a wall that is radiused or otherwise transitioned from the base of the blade (at the multi-piece bit body) to the top face 335. For example, a first end 332 may include a sloped, curved, or substantially perpendicular wall extending from the multi-piece (e.g., two-piece) bit body to the top face 335 of the blade 330. The first end 332 of each blade 330 is at a second radial distance 335 from the longitudinal axis 312 (measured from the longitudinal axis 312 to the base of the first end 332). As shown, the first end 332 of each blade 330 is at an equal second radial distance 335 from the longitudinal axis 312. However, the first ends of a plurality of blades may be at different radial distances from the longitudinal axis (for example, as illustrated in FIG. 1, where blades 130 aligned with the roller cones 120 have a larger second radial distance than blades 130 located between adjacent roller cones 120). A second radial distance may range between  $1/4$  and  $1/2$  of the bit radius from the longitudinal axis. In some embodiments, a second radial distance may range from greater than  $1/4$  of the radial distance to the bit gauge from the longitudinal axis. In some embodiments, a second radial distance may range from greater than  $1/3$  of the radial distance to the bit gauge from the longitudinal axis. In some embodiments, a second radial distance may range from greater than  $1/2$  of the radial distance to the bit gauge from the longitudinal axis. Further, in some embodiments, a



second radial distance may range from greater than  $2/3$  of the radial distance to the bit gauge from the longitudinal axis. The second radial distance may be designed based on the first radial distance to provide an overlapping journal/blade profile in the radial direction. In such embodiments, in addition to the first and second radial distances, the journal size and angle of journal extension may also be adjusted such that the radial distance from the bit longitudinal axis to the radially outermost point of the journal is larger than the second radial distance.

[0092] Referring again to FIGS. 12 and 13, a plurality of blade cutting elements 135 are disposed on each blade 130, and a plurality of roller cone cutting elements 125 are disposed on each roller cone 120. As shown, the blade cutting elements 135 have planar cutting faces, while the roller cone cutting elements 125 have non-planar cutting faces 125. However, different types of cutting elements may be used on the blades 130 and roller cones 120. For example, both blade cutting elements and roller cone cutting elements may have planar cutting faces. Cutting elements used with hybrid drill bits of the present disclosure may include polycrystalline diamond compacts (PDCs), diamond grit impregnated inserts (“grit hot-pressed inserts” (GHIs)), natural diamond, milled steel teeth, tungsten carbide inserts (TCIs), diamond enhanced inserts (DEIs), or conical shaped (or other substantially pointed) cutting elements.

[0093] The blade cutting elements may include primary cutting elements and backup cutting elements (e.g., elements that “back up” or are rotationally behind a primary cutting element, and having a radial position approximately equal to that of the primary cutting element). In some embodiments, the primary and backup cutting elements may be located on a single blade, while in other embodiments, the primary cutting elements may be located on a primary blade (that extends from adjacent the cavity to the gage) and the backup cutting elements may be located on a secondary blade. In other embodiments, primary cutting elements may be located on both primary and secondary blades (and e.g., no backup cutting elements are used). The primary cutting elements and backup cutting elements may be the same or different. Similarly, the primary cutting elements located on the primary blades and the primary cutting elements located on the secondary blades may be the same or different. In some embodiments, the primary cutting elements (or primary cutting elements on the primary blade) may have a planar cutting face and the backup cutting elements (or primary cutting elements on the secondary blade) may have a conical shape, and in other

embodiments, the primary cutting elements (or primary cutting elements on the primary blade) may have a conical shape and the backup cutting elements (or primary cutting elements on the secondary blade) may have a planar cutting face. In some embodiments, the primary cutting elements (or primary cutting elements on the primary blade) may have a non-planar upper surface with an elevated crest extending substantially across the diameter of the cutting element (e.g., having a substantially hyperbolic paraboloid shape or substantially parabolic cylinder shape), and the backup cutting elements (or primary elements on the secondary blade) may have a conical shape, or in other embodiments the primary cutting elements (or primary cutting elements on the primary blade) may have a conical shape, and the backup cutting elements (or primary elements on the secondary blade) may have a non-planar upper surface with an elevated crest extending substantially across the diameter of the cutting element (e.g., having a substantially hyperbolic paraboloid shape or substantially parabolic cylinder shape). However, any combination of blade cutting elements may be used in the blade portion and, e.g., different shaped cutting elements may be included as primary cutting elements on a single blade.

[0094] The blade cutting elements 135 form a blade cutting profile, and the roller cone cutting elements 125 form a roller cone cutting profile. As used herein, a cutting profile (e.g., a blade cutting profile and a roller cone cutting profile) refers to the profile or outline of cutting elements as they would appear in rotated view, i.e., when the bit rotated about its longitudinal axis and the roller cones are rotated about their rotational axes. For example, FIG. 15 shows a cutting profile 400 of a hybrid drill bit according to embodiments of the present disclosure. The cutting profile 400 includes a blade cutting profile 430 and a roller cone cutting profile 420. The roller cone cutting profile 420 may extend a radial distance 426 from the longitudinal axis 412 of the hybrid drill bit or a point near the longitudinal axis to an outer diameter 427 of the roller cone cutting profile 420, and the blade cutting profile 430 may extend a radial distance 436 from an inner diameter 435 of the blade cutting profile 430 to an outer diameter 437 of the blade cutting profile 430. According to embodiments of the present disclosure, the outer diameter 437 of the blade cutting profile 430 may be at the gauge of the bit. The roller cone cutting profile 420 may radially overlap with the blade cutting profile 430 within the radial extent of a first row 422 of roller cone cutting elements (i.e., the row of cutting elements positioned farthest from the roller cone base). In some embodiments, the roller cone cutting profile 420 may radially overlap with the blade cutting

profile within a distance 446, which may be equal to  $\sin(\text{journal angle}) \times (\text{diameter of the first row})$ . That is, the overlap may range from within the end points of that distance 446. For example, a roller cone cutting profile may radially overlap with the blade cutting profile a distance ranging from less than 0.1 inches (2.5 mm) in some embodiments and less than 1.5 inches (38.1 mm) in some embodiments. According to some embodiments of the present disclosure, the roller cone cutting profile may not radially overlap the blade cutting profile. In such embodiments, the roller cone cutting profile may be radially adjacent to the blade cutting profile, or the roller cone cutting profile may be located a radial distance apart from the blade cutting profile. In other embodiments, the blade cutting profile may overlap with the first row cutting element profile of the roller cone cutting profile. Further, in one or more embodiments, the blade cutting profile may overlap with the first row cutting element profile, but when considering the roller cone cutting elements that are engaging with the bottom hole, there is no overlap. That is, the overlap is with cutting elements that are rotated in an off-bottom position. However, in one or more other embodiments, the blade cutting profile may overlap with roller cone elements that are rotated in an on-bottom position. The cutting profile of FIG. 15 also includes a central cutting element 460.

[0095] FIGS. 16-18 show a bottom view, a side view, and a cutting profile of another hybrid drill bit formed using methods of the present disclosure. The bit 3200 has a multi-piece bit body 3201, a longitudinal axis 3202 extending through the bit body 3201, at least one blade 3210 protruding from the bit body, where the at least one blade 3210 extends an axial distance along a gauge 3204 of the bit body and a radial inward distance from the gauge towards the longitudinal axis 3202, a plurality of blade cutting elements 3212 disposed on the blades 3210 and forming a blade cutting profile, at least one journal (shown in FIG. 18 as 3230) extending downwardly from the bit body 3201, a roller cone 3220 rotatably mounted to each journal, and a plurality of roller cone cutting elements 3222 disposed on each roller cone 3220 and forming a roller cone cutting profile. As shown, the roller cones 3220 and roller cone cutting elements 3222 disposed thereon do not extend to the gauge 3204 of the bit 3200. According to some embodiments of the present disclosure, a journal portion may further include a center cutting element disposed between the two or more journals extending from the journal end of the journal portion, as shown in FIG. 16, as well as FIGS. 19 and 20, which show the journal portion of the bit illustrated in FIGS. 16 and 17. For example, in some embodiments, a center cutting element 3230 may be disposed along the longitudinal

axis of the journal portion 3202, such that a longitudinal axis of the center cutting element 3230 is coaxial with the longitudinal axis of the journal portion. In other embodiments, a center cutting element may be disposed in a hole 3232 (shown in FIG. 19) between two or more journals 304 on the journal end 303 of the journal portion 300, such that the center cutting element 3230 extends from the journal portion 300 in a direction facing away from the attachment end 302 of the journal portion 300. A center cutting element 3230 may be assembled to a journal portion 300, for example, by brazing or interference fitting a cutting element within a cutter hole 3232 formed in the journal portion 300. A center cutting element 3230 may be formed of various materials and have various shapes and sizes. For example, in some embodiments, a center cutting element may have a conical shaped cutting surface, i.e., the surface that is exposed from the journal portion and that contacts a workpiece surface, where the conical cutting surface has an apex with a radius of curvature. In some embodiments, a center cutting element may be formed of a carbide material, a carbide substrate with a diamond layer thereon forming the cutting layer, or other ultrahard material, and combinations thereof.

[0096] FIG. 18 shows a rotated cutting profile view of the bit 3200 shown in FIGS. 16 and 17. As shown, the roller cone cutting elements 3222 disposed on the roller cones 3220 form a roller cone cutting profile 3224, and the blade cutting elements 3212 form a blade cutting profile 3214. The roller cone cutting profile 3224 may extend a radial distance from a point near the longitudinal axis 3202 to an outer diameter 3227 of the roller cone cutting profile 3224, where the outer diameter 3227 of the roller cone cutting profile 3224 is a distance inward from the bit gauge 3204. The blade cutting profile 3214 may extend a radial inward distance from the gauge 3204 of the bit to an inner diameter 3215 of the blade cutting profile 3214. The radial distance of the roller cone cutting profile 3224 may radially overlap with the radial inward distance of the blade cutting profile 3214 a distance ranging up to  $\frac{3}{4}$  of the bit radius (where the bit radius is measured from the longitudinal axis to the bit gauge).

[0097] Further, as shown in FIG. 18, a plurality of the roller cone cutting elements 3222 along the on-bottom position may radially overlap with a plurality of blade cutting elements 3212 along the on-bottom position. As used herein, an on-bottom position may refer to the position at which cutting elements contact or extend in the direction towards the bottom, or axially lowest part, of the wellbore. In cases of directional drilling, an on-bottom position may refer to the position at which cutting elements contact or extend towards a formation

face in the direction of drilling. As shown, the roller cone cutting profile 3224 along the on-bottom position radially extends from a first end 3226 to a second end 3228, where the second end 3228 is located a radial distance inward from the gauge 3204 and a radial distance inward from the roller cone outer diameter 3227. The blade cutting profile 3214 along the on-bottom position extends a radial inward distance overlapping with the roller cone cutting profile 3224 along the on-bottom position, where the on-bottom radially overlapping distance 3240 may range from greater than the radius of a blade cutting element and/or roller cone cutting element to less than  $\frac{3}{4}$  of the bit radius. In some embodiments, an on-bottom radially overlapping distance between a roller cone cutting profile and a blade cutting profile may range from greater than  $\frac{1}{4}$  of the bit radius. In some embodiments, an on-bottom radially overlapping distance between a roller cone cutting profile and a blade cutting profile may range from  $\frac{1}{2}$  to  $\frac{3}{4}$  of the bit radius.

[0098] Referring still to FIG. 18, the roller cones 3220 may have an extension length 3221 and a diameter 3223, where the diameter 3223 decreases from the roller cone base along the extension length 3221. As shown, the roller cones 3220 may have an extension length 3221 that is equal to or greater than the largest diameter 3223 along the extension length 3221. According to embodiments of the present disclosure, roller cones may have an extension length to diameter ratio ranging from 0.5 to 2, where the extension length is measured from the base of the roller cone to the apex (opposite the base) of the roller cone, and where the diameter is measured along the widest portion of the extension length. In some embodiments, such as the one shown in FIGS. 16-18, the extension length to diameter ratio may range from about 0.7 to 1.1. In some embodiments, the extension length to diameter ratio may range from about 0.5 to 0.8. Further, in embodiments using roller cones with a larger extension length to diameter ratio, the roller cone may extend to near or overlap with the nose region of a blade. As used herein, a nose region of a blade may refer to the region around the point along a convex region of the blade profile in rotated profile view at which the slope of a tangent to the blade profile is zero. For example, as shown in FIG. 18, the roller cone 3220 extends radially past (and overlaps with) the nose region 3216 of the blade cutting profile 3214.

[0099] Using roller cones with a larger extension length to diameter ratio may allow for greater cutting profile overlap. For example, according to embodiments of the present disclosure, a blade cutting profile may radially overlap with a roller cone cutting profile up to the entire

radial length of the roller cone cutting profile. In some embodiments, a blade cutting profile may radially overlap with a roller cone cutting profile ranging from a lower limit of  $1/8$ ,  $1/4$ ,  $1/3$  or  $1/2$  of the roller cone extension length to an upper limit of  $1/4$ ,  $1/3$ ,  $1/2$ ,  $2/3$ ,  $3/4$  or  $9/10$  of the roller cone extension length, where any lower limit can be used in combination with any upper limit. Further, a blade cutting profile may radially overlap with a roller cone up to the entire roller cone extension length. For example, in some embodiments, a hybrid bit may include a roller cone mounted to a journal positioned at a journal angle of 0 degrees and at least one blade extending axially along the bit gauge and a distance radially inward from the bit gauge, where the roller cone has an extension length less than the bit radius (such that the roller cone does not extend to the gauge of the bit), and where the radial inward distance of the blade overlaps the entire roller cone extension length.

[00100] According to embodiments of the present disclosure, the radial distance from an assembled multi-piece bit longitudinal axis to the radially outermost point of a journal may overlap with the radial distance from the bit gauge to the first end of a blade, such that the radial distance from the bit longitudinal axis to the radially outermost point of the journal extends at least to the radius of a first blade cutting element (i.e., a cutting element positioned closest to the first end of the blade). In some embodiments, the radial distance from the bit longitudinal axis to the radially outermost point of a journal may extend past at least  $3/4$  of a first blade cutting element in a blade cutting profile. In some embodiments, the radial distance from the bit longitudinal axis to the radially outermost point of a journal may extend to at least the entire diameter of a first blade cutting element in a blade cutting profile. In some embodiments, the radial distance from the bit longitudinal axis to the radially outermost point of a journal may extend past more than the first three blade cutting elements along the blade cutting profile (i.e., past the three blade cutting element positions radially closest to the bit longitudinal axis), for example, past four blade cutting elements, past five blade cutting elements, or more. In embodiments having the radial distance from the bit longitudinal axis to the radially outermost point of a journal extend radially past at least a portion of a first cutting element of a blade cutting profile, a portion of the roller cone cutting profile overlaps with a portion of the blade cutting profile, such that at least one roller cone cutting element and at least one blade cutting element has shared cutting duties (i.e., may both cut along a shared radial path). In other words, in embodiments having a portion of the roller cone cutting profile overlap with a portion of the blade cutting profile, the radially

outermost roller cone cutting elements may have shared cutting duties with the radially innermost blade cutting elements. The number of roller cone cutting elements and blade cutting elements having shared cutting duties may depend on how much radial overlap the roller cone cutting profile and blade cutting profile have.

[00101] Further, in one or more embodiments, the blade cutting profile may form at least a gauge region of the bit, and may extend radially inward into what would be considered a shoulder region (as that term is used in conventional fixed cutter bits). That is, each blade cutting element is at an axially lower position relative to the radially outer “adjacent” (when viewed in a rotated profile view) blade cutting element. Further, depending on the shape and curvature of blades (and location of cutting elements), the axially lowermost blade cutting element may not be the radially most interior blade cutting element, as illustrated in FIG. 5, for example. In such an embodiment, the blade cutting profile extends through the shoulder, into what would be considered a nose region.

[00102] Radial positions of roller cone and blade cutting profiles may be designed based on the axial positions of the roller cone and blade cutting profiles. According to embodiments of the present disclosure, the blade cutting profile may axially overlap the roller cone cutting profile by up to 100 percent of the roller cone cutting profile. For example, the blade cutting profile may extend an axial distance along the bit that axially overlaps with up to  $\frac{3}{4}$  the axial distance of the roller cone cutting profile. In some embodiments, the blade cutting profile may extend substantially to the same axial distance as the roller cone cutting profile to overlap with substantially the entire axial distance of the roller cone cutting profile. In some embodiments, the blade cutting profile may extend an axial distance past the axially lowest point of the roller cone cutting profile. According to embodiments of the present disclosure, a journal portion and blade portion cavity may be designed to provide a desired axial overlap between the blade cutting profile and roller cone cutting profile. For example, in embodiments having a blade cutting profile extending an axial distance past the axially lowest point of the roller cone cutting profile, the journal portion may be designed to have a relatively larger length than the cavity formed in the corresponding blade portion, the axial extension of the journals extending from the journal portion may be increased, and/or the diameter of the roller cones mounted to the journals may be increased. In embodiments having a blade cutting profile extending an axial distance along the bit that axially overlaps with up to  $\frac{3}{4}$  the axial distance of the roller cone cutting profile, the journal portion may be

designed to have a relatively shorter length than the cavity formed in the corresponding blade portion, the axial extension of the journals extending from the journal portion may be decreased, and/or the diameter of the roller cones mounted to the journals may be decreased.

[00103] Embodiments of the present disclosure may include roller cone cutting profiles and blade cutting profiles that are axially and radially positioned to axially and/or radially overlap. For example, a bit may have a blade cutting profile that axially overlaps the lowest axial point of the base of a journal, where the roller cone cutting profile radially overlaps the blade cutting profile by at least the radius of the first cutting element of the blade cutting profile.

[00104] According to embodiments of the present disclosure, a drill bit may include a bit body having a longitudinal axis extending there through, at least one blade extending from the bit body, a plurality of blade cutting elements disposed on the at least one blade, where the blade cutting elements form a blade cutting profile, at least one journal extending downwardly from the bit body, a roller cone rotatably mounted to each of the at least one journals, and a plurality of roller cone cutting elements disposed on each roller cone, where the roller cone cutting elements form a roller cone cutting profile, and where the roller cone cutting profile extends an axial height greater than the blade cutting profile.

[00105] For example, referring again to FIG. 15, a cutting profile 400 of a hybrid drill bit includes a blade cutting profile 430 and a roller cone cutting profile 420, where the roller cone cutting profile 420 extends an axial height 450 greater than the blade cutting profile 430 (i.e., the roller cone cutting profile 420 extends axially lower than the blade cutting profile 430). The axial height 450 between the roller cone cutting profile 420 and the blade cutting profile 430 may range within the axial extent of the first row 422 of roller cone cutting elements. In some embodiments, the axial height 450 between the roller cone cutting profile 420 and the blade cutting profile 430 may range from greater than 0.1 inches (2.5 mm). For example, in some embodiments, the axial height between a roller cone cutting profile and a blade cutting profile may range from about 0 to about 3 inches (76.2 mm), or with a lower limit of any of 0.25 (6.35 mm), 0.5 (12.7 mm), 1.0 (25.4 mm), or 1.5 inches (38.1 mm), and an upper limit of any of 1.5 (38.1 mm), 2.0 (50.8 mm), 2.5 (63.5 mm), 2.75 (69.85 mm) or 3.0 inches (76.2 mm), where any lower limit can be used with any upper limit. In one or more embodiments, the blade cutting elements may have at least one axial overlap with at least one roller cone cutting element when that roller cone cutting element is rotated in an on-bottom position.



[00106] According to some embodiments of the present disclosure, a hybrid drill bit may include a bit body having a longitudinal axis extending there through, at least one blade protruding from the bit body, where the at least one blade extends an axial distance along a gauge of the bit body and a radial inward distance from the gauge towards the longitudinal axis, at least one journal extending downwardly from the bit body, where the at least one journal extends a length from a base of the journal, and a roller cone rotatably mounted to the at least one journal, where the lowest axial point of the at least one blade is axially lower than the lowest axial point of the base of the journal. In some embodiments having the lowest axial point of a blade that is axially lower than the lowest axial point of the base of the journal, the blade may axially overlap the lowest axial point of the base of the journal. In other embodiments having the lowest axial point of a blade that is axially lower than the lowest axial point of the base of the journal, the journal may be inset within the bit such that the blade does not axially overlap the lowest axial point of the base of the journal.

[00107] According to some embodiments of the present disclosure, the axial position of one or more journals and roller cones mounted thereon may be inset from the axial position of one or more blades, such that the lowermost axial position of the blade cutting profile extends axially lower than the lowermost axial position of the roller cone cutting profile. In such embodiments, the blade cutting profile may axially overlap with 100% of the roller cone cutting profile. As used herein, the terms “lowermost” or “downward” refers to a direction facing away from the connection end of a bit and towards the bit cutting face. In some embodiments having the lowermost axial position of the blade cutting profile extending axially lower than the lowermost axial position of the roller cone cutting profile, the multi-piece bit body may be formed of a journal portion having a total length (measured from the end surface of the attachment end to the lowermost point of a journal extending from the journal end) that is less than the total length of the corresponding blade portion.

[00108] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this disclosure. Accordingly, all such modifications are intended to be included within the scope of this disclosure. It is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words ‘means for’ together with an associated function.

## CLAIMS

What is claimed is:

1. A method of manufacturing a drill bit, comprising:
  - inserting an attachment end of a journal portion into a cavity of a blade portion,
  - the journal portion comprising:
    - the attachment end;
    - a journal end opposite from the attachment end; and
    - a journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion, and
  - the blade portion comprising:
    - the cavity extending a distance into the blade portion; and
    - at least one blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit;
  - attaching the journal portion to the blade portion; and
  - mounting a roller cone to the journal.
2. The method of claim 1, wherein prior to inserting the journal portion into the cavity, the method further comprises disposing at least two o-rings around the attachment end, each two adjacent o-rings defining a lubrication section.
3. The method of claim 2, wherein a lubrication channel extends from the lubrication section through the journal portion to the journal end.
4. The method of claim 2, wherein the blade portion comprises a lubrication reservoir and a passageway extending from the lubrication reservoir to the cavity, and wherein upon attaching the journal portion to the blade portion, the passageway opens to the lubrication section.
5. The method of claim 1, wherein attaching comprises inserting at least one locking pin through the blade portion and into the journal portion.

6. The method of claim 1, wherein the blade portion is formed from a different material than the journal portion.
7. The method of claim 6, wherein the journal portion is formed of a heat treatable steel.
8. The method of claim 6, wherein the blade portion is formed of a matrix material.
9. The method of claim 1, wherein the journal portion further comprises a locking segment formed by a plurality of intersecting outer side surfaces, the locking segment being between the attachment end and the journal end, and wherein upon inserting the journal portion into the cavity, the locking segment mates with a plurality of inner surfaces of the cavity.
10. The method of claim 1, wherein the end of the at least one blade adjacent to the cavity is at a radial distance of 0 to 20% of the drill bit diameter from the cavity.
11. The method of claim 1, further comprising disposing a center cutting element on the journal portion along the longitudinal axis of the journal portion.
12. A method of manufacturing a drill bit, comprising:
  - determining a primary torque transfer area between a journal portion and a blade portion of a multi-piece bit body; and
  - inserting an attachment end of the journal portion into a cavity of the blade portion to form the multi-piece bit body,the journal portion comprising:
  - an attachment end;
  - a journal end opposite from the attachment end;
  - a journal on the journal end extending downward and radially outward from a longitudinal axis of the journal portion;
  - a locking segment formed of a plurality of intersecting outer side surfaces around the journal portion, the locking segment being between the attachment end and the journal end, a total outer side surface area of the locking segment being equal to or greater than the primary torque transfer area, andthe blade portion comprising:
  - the cavity extending a distance into the blade portion; and

a blade extending along the blade portion from adjacent to the cavity to a gauge region of the drill bit.

13. The method of claim 12, further comprising inserting a locking pin through the blade portion and into the attachment end of the journal portion.
14. The method of claim 13, further comprising determining a secondary torque transfer between the multi-piece bit body, wherein the secondary torque transfer is determined using the cross sectional area, the torque section radius, and the material yield strength of the locking pin to calculate a pin torque capacity of the locking pin.
15. The method of claim 12, further comprising designing a weight-on-bit transfer plane, the weight-on-bit transfer plane comprising the contact area between a base surface of the locking segment and a mating surface of the cavity.
16. The method of claim 12, wherein the locking segment is formed by machining the plurality of intersecting outer surfaces to fit within the cavity.
17. The method of claim 12, wherein the journal portion comprises a ball hole, and the ball hole opens to a race surface of one of the journal.
18. The method of claim 12, wherein the journal portion is formed of a different material than the blade portion.
19. The method of claim 12, further comprising welding a threaded connection to the blade portion at an end opposite from the cavity.
20. The method of claim 12, further comprising attaching a roller cone to the journal.

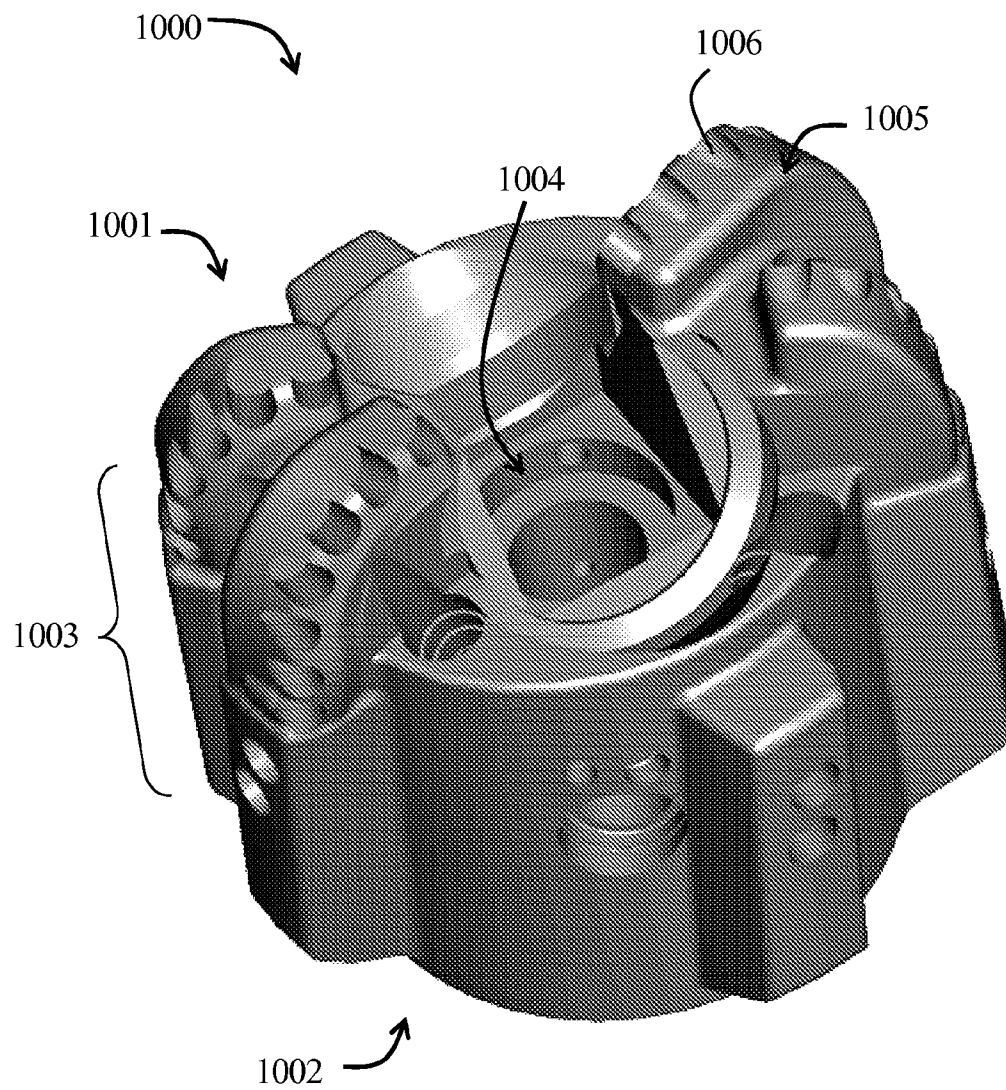


FIG. 1

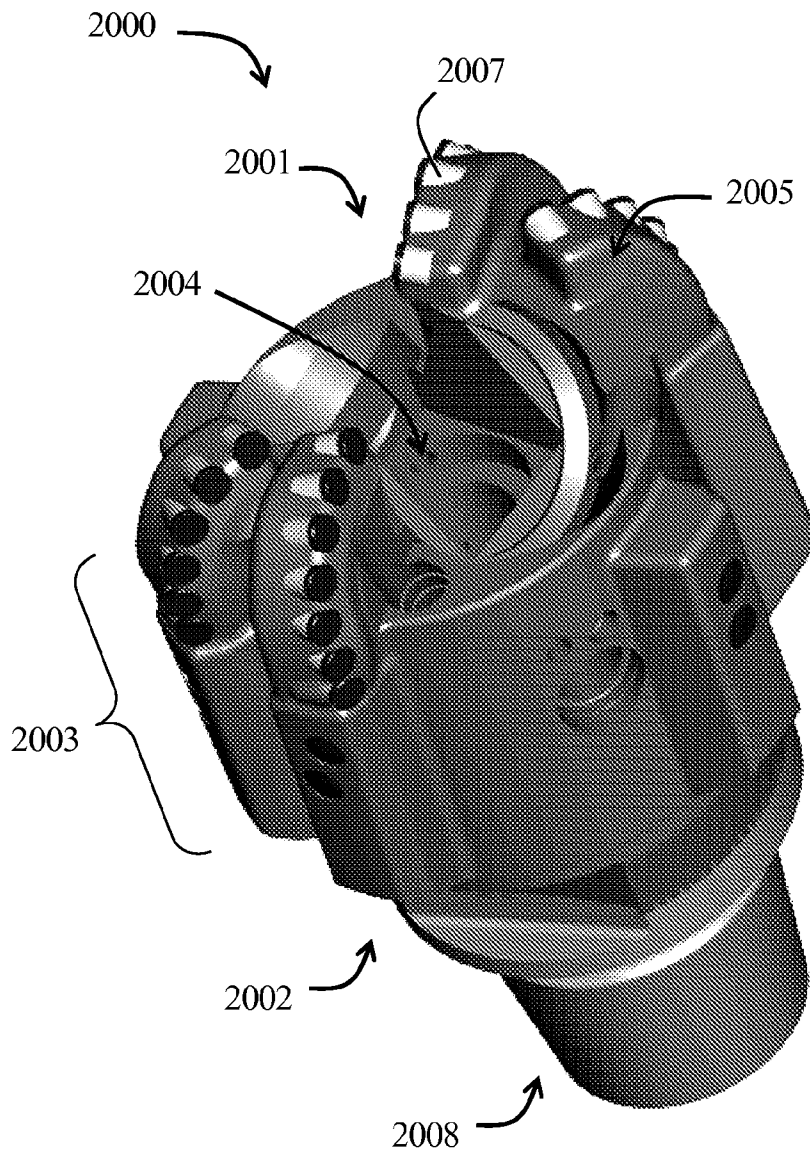


FIG. 2

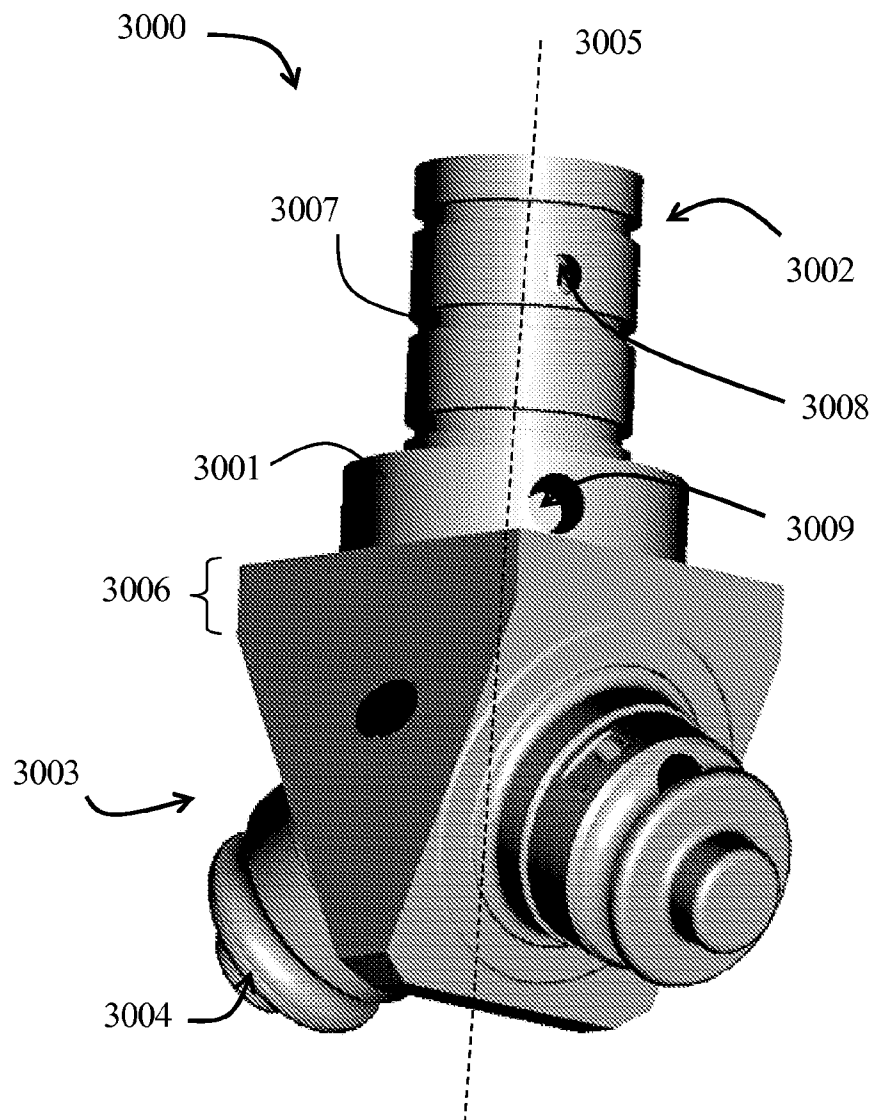


FIG. 3

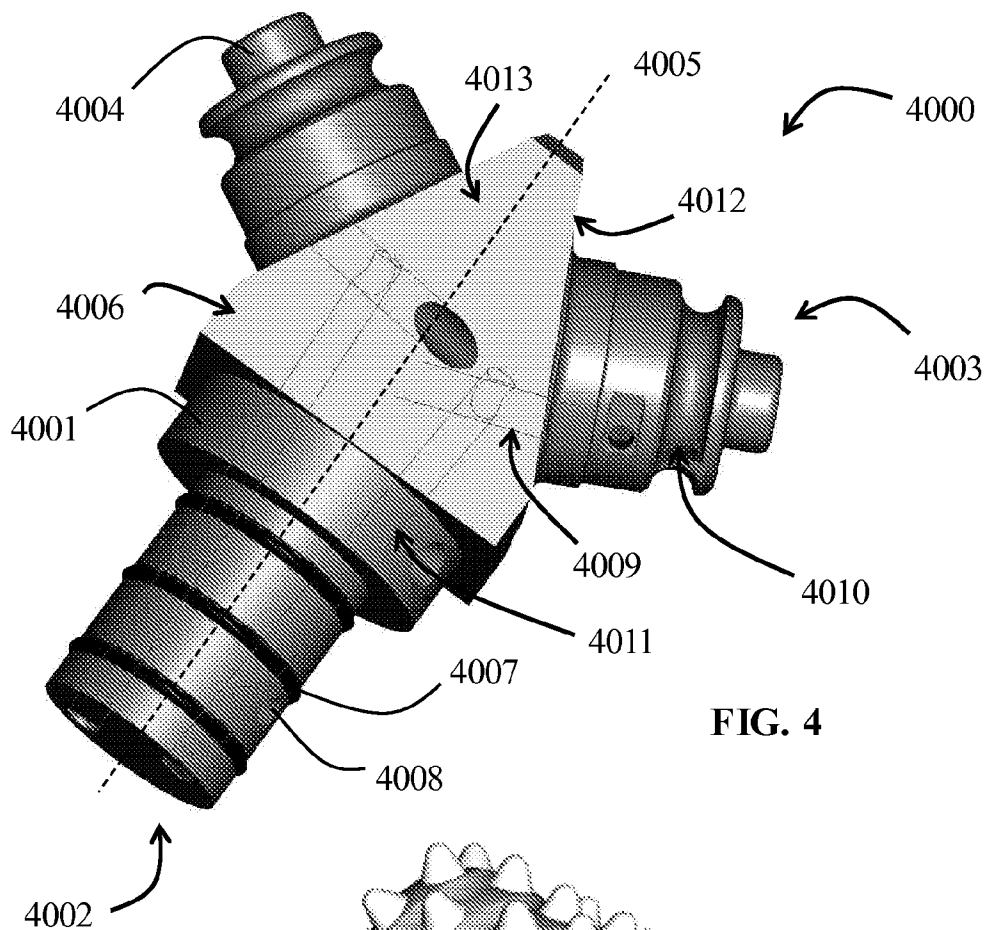


FIG. 4

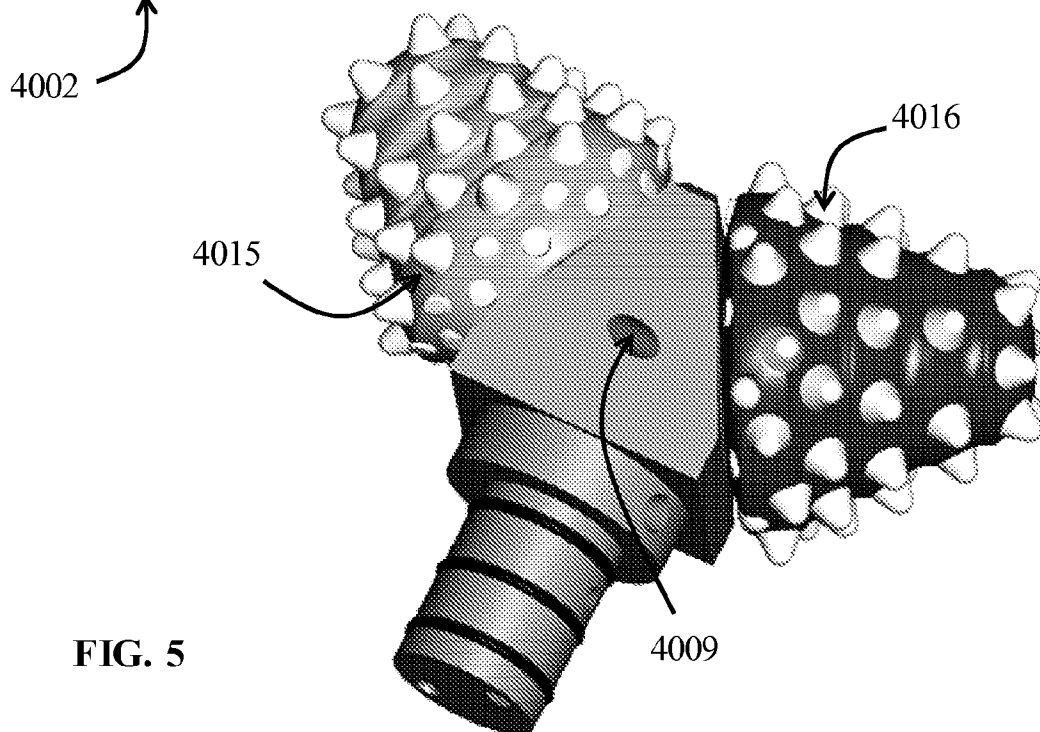


FIG. 5



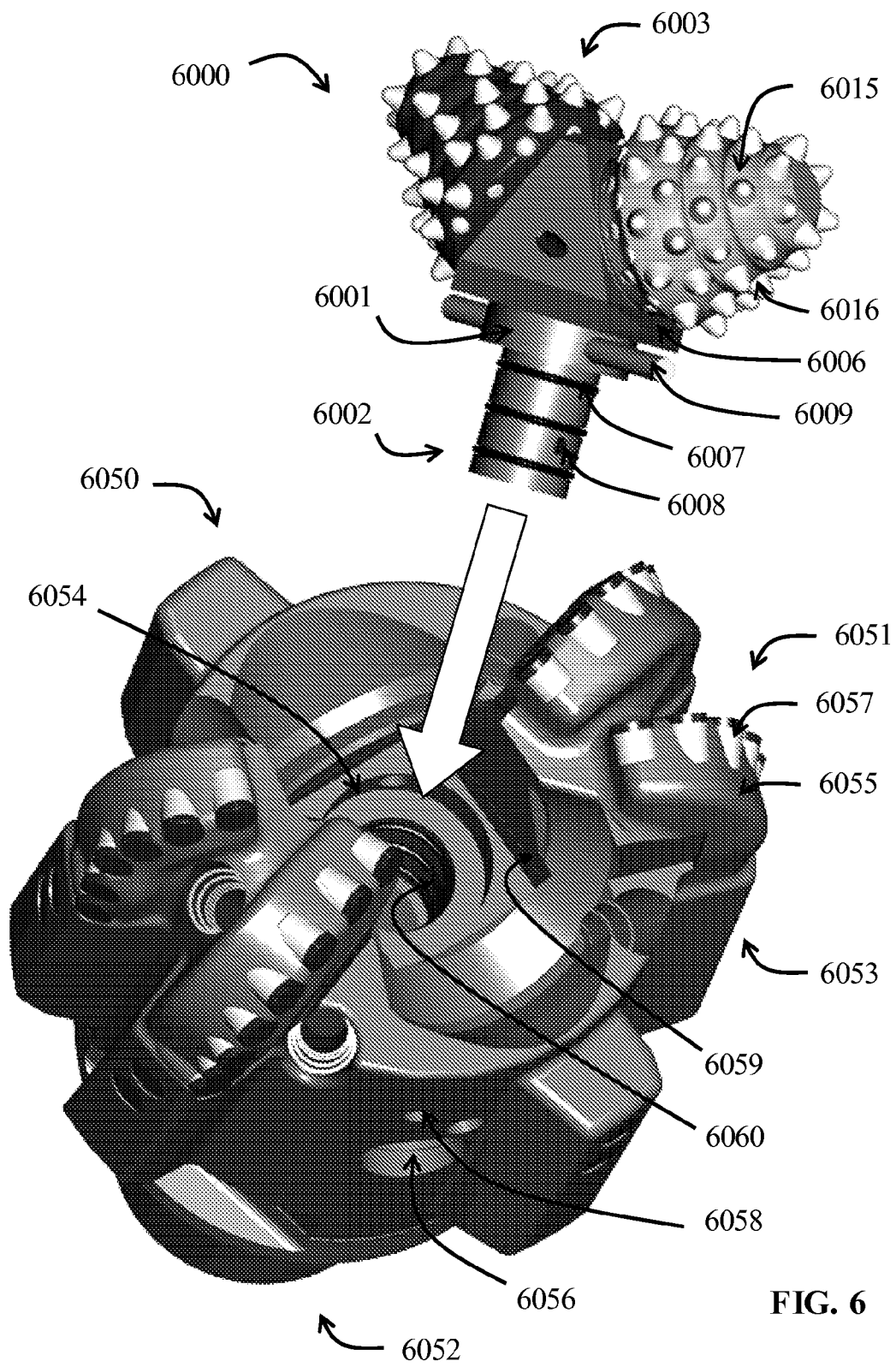
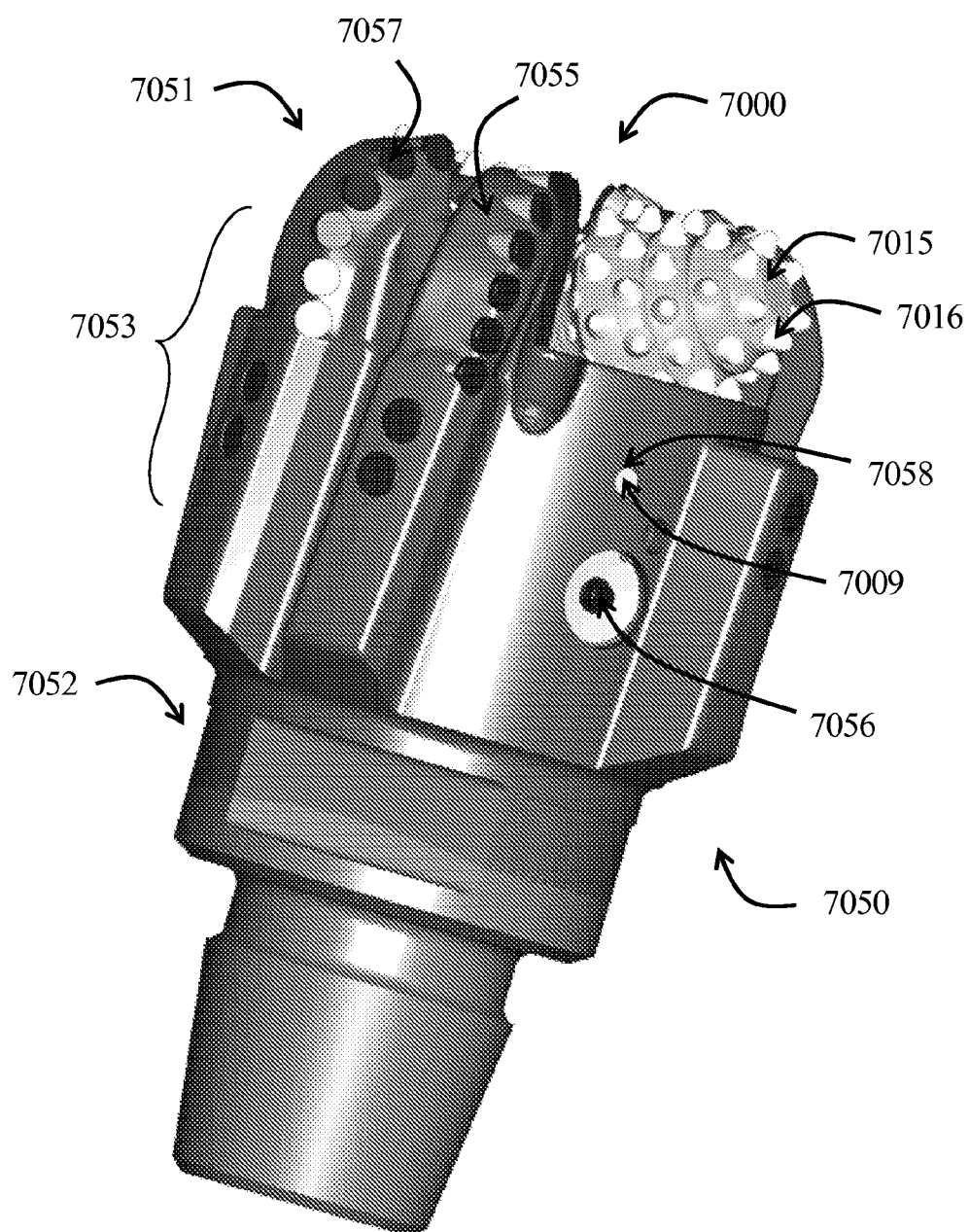


FIG. 6



**FIG. 7**

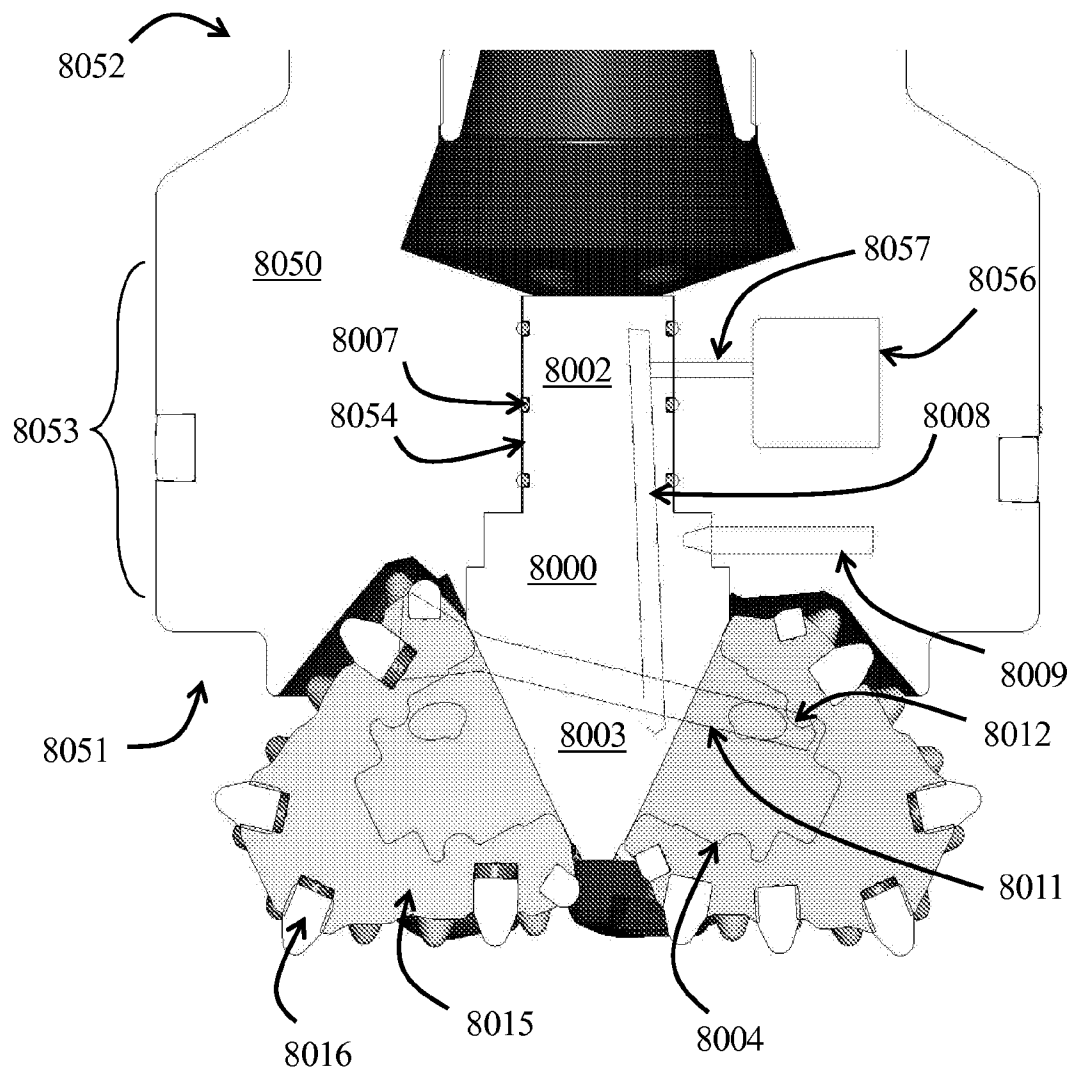


FIG. 8

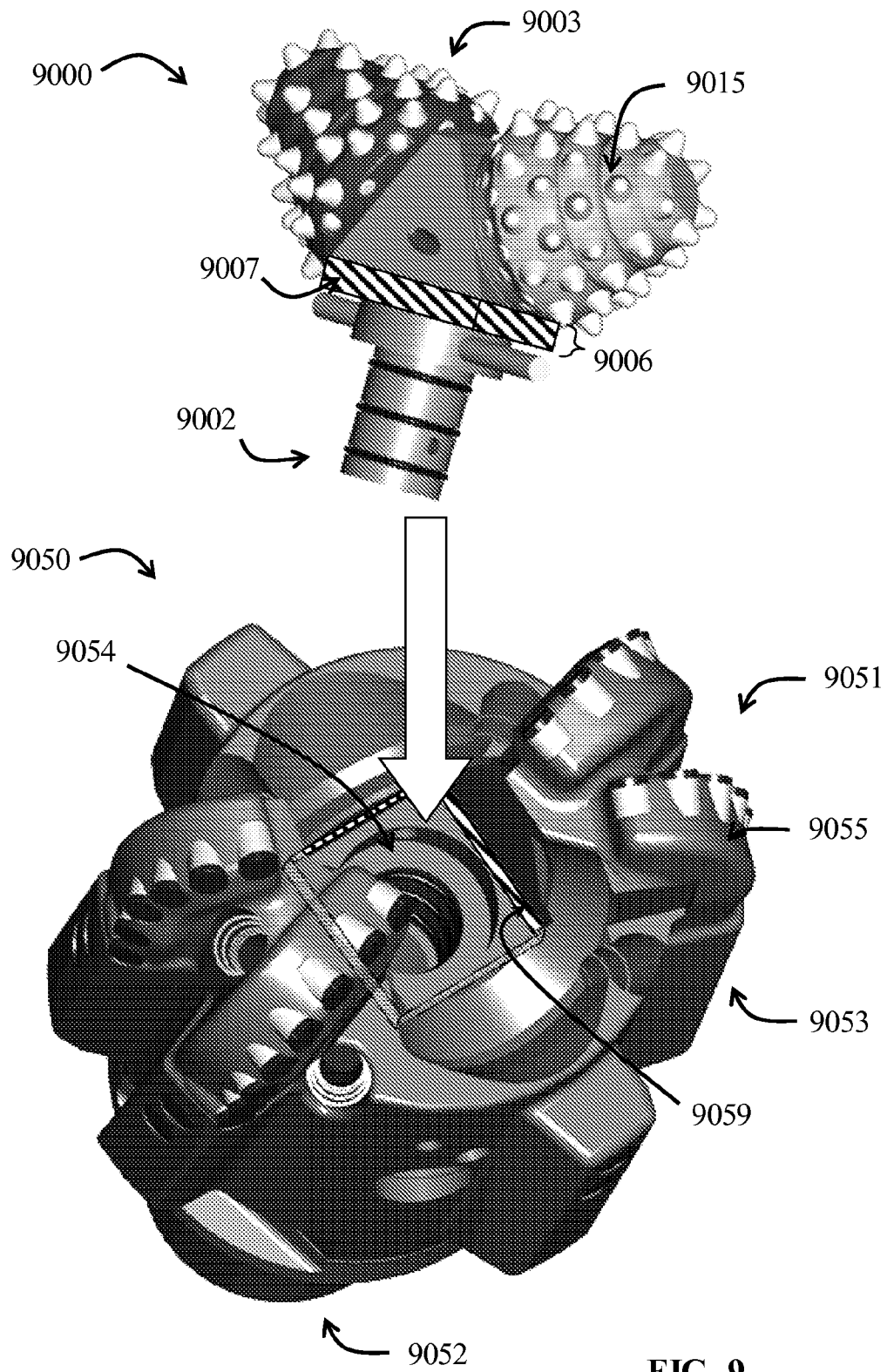
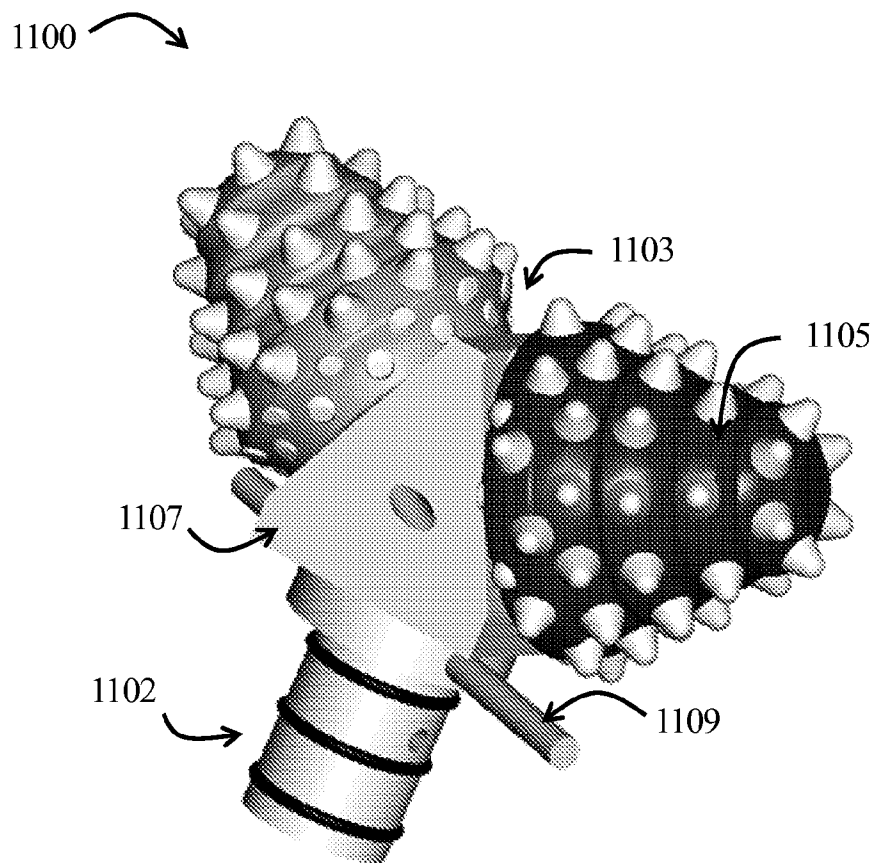


FIG. 9

**FIG. 10**

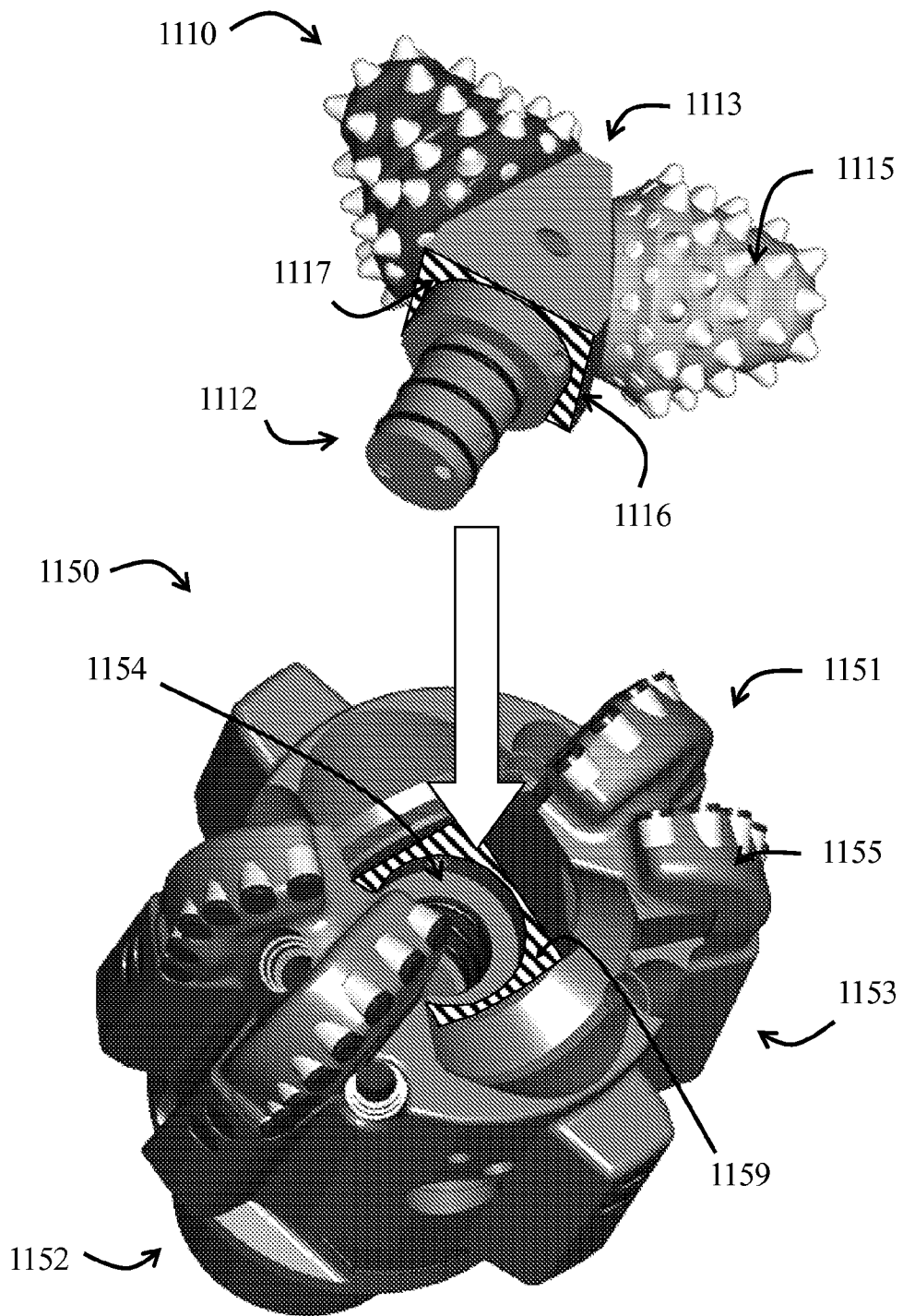


FIG. 11

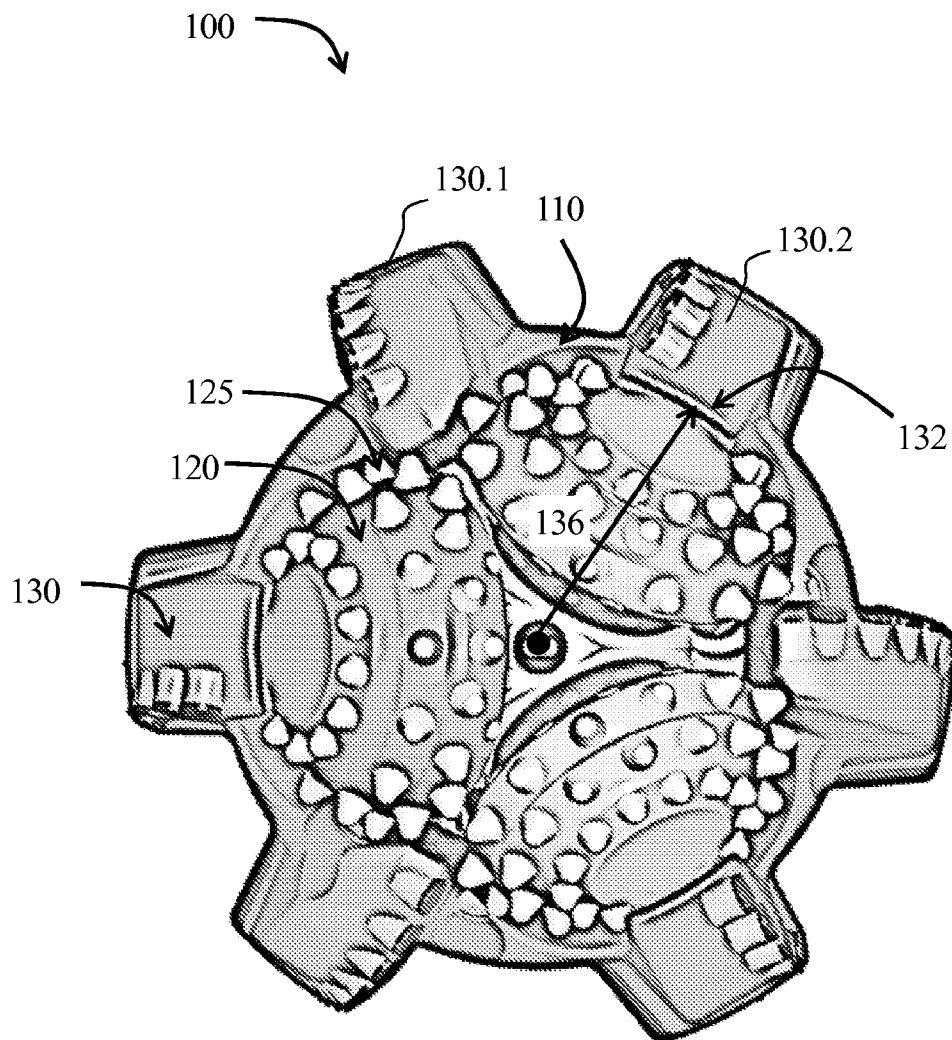


FIG. 12

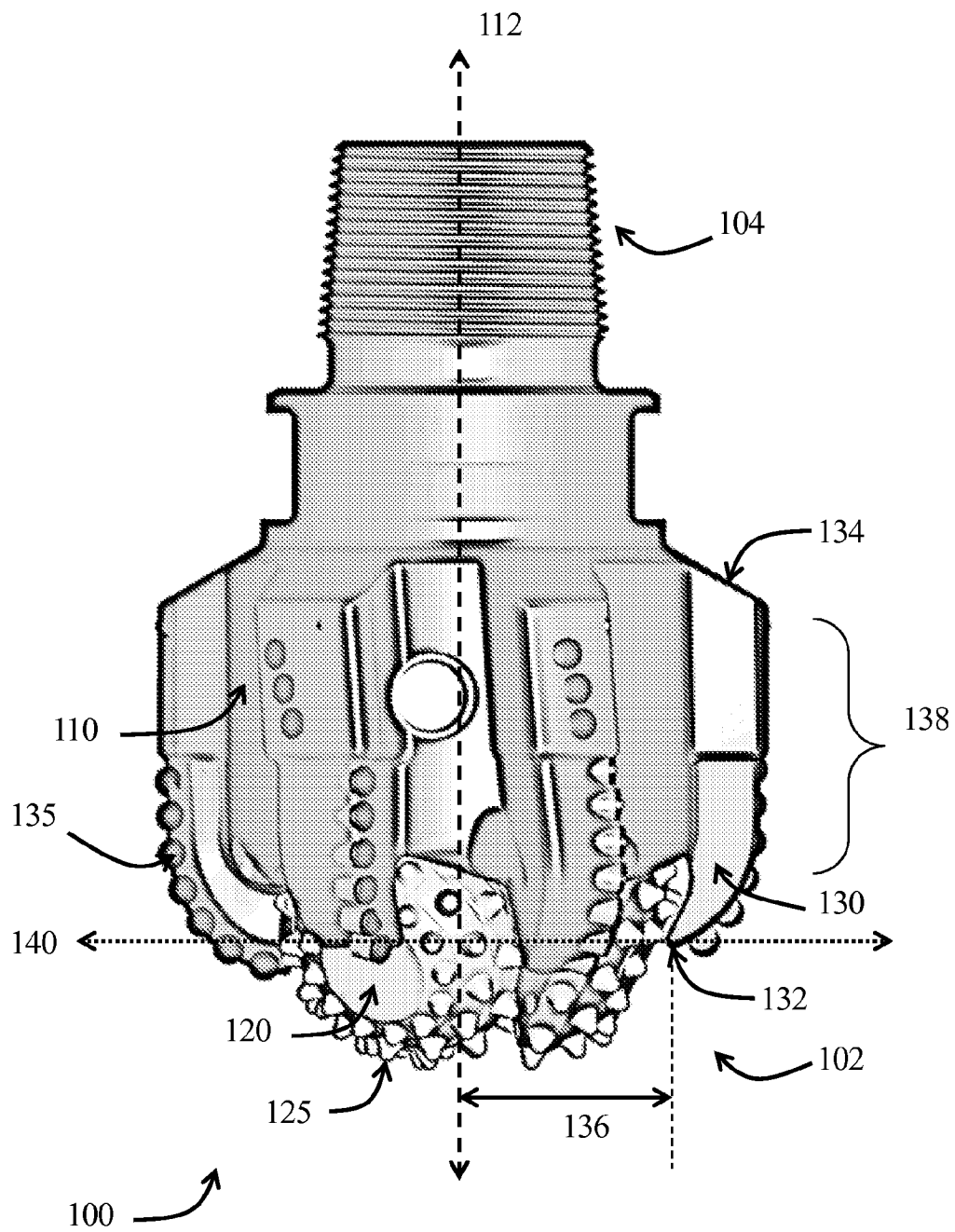


FIG. 13



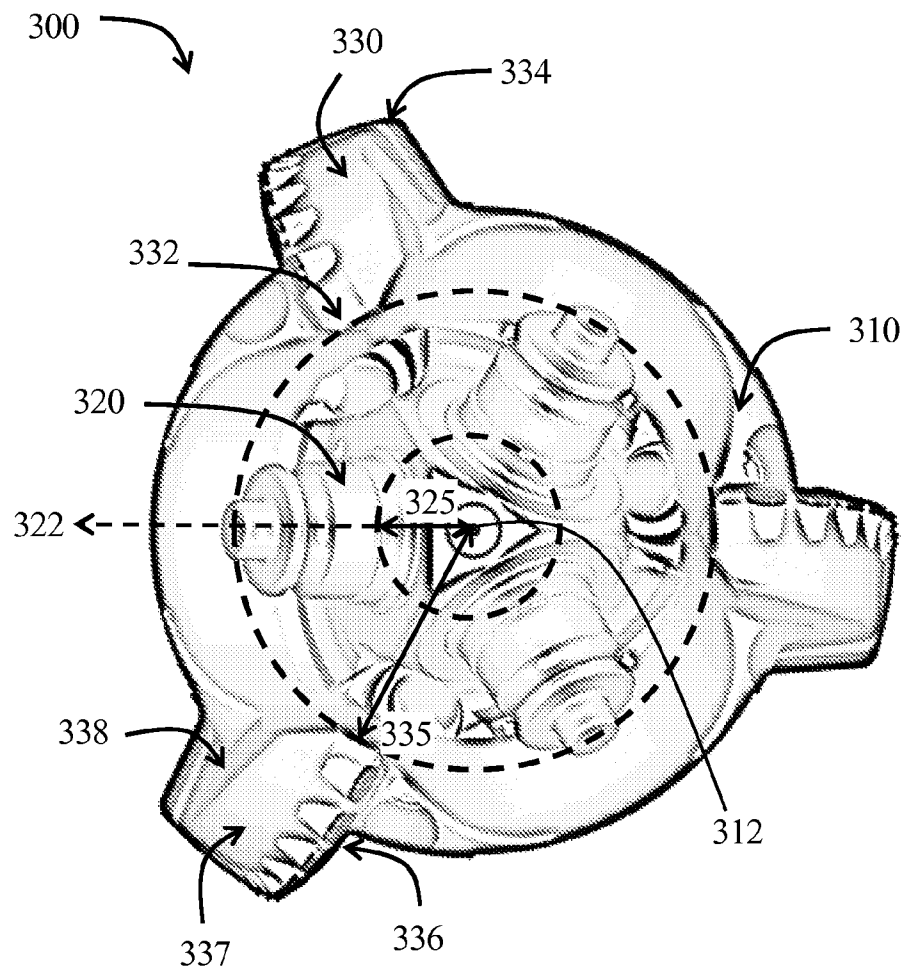


FIG. 14

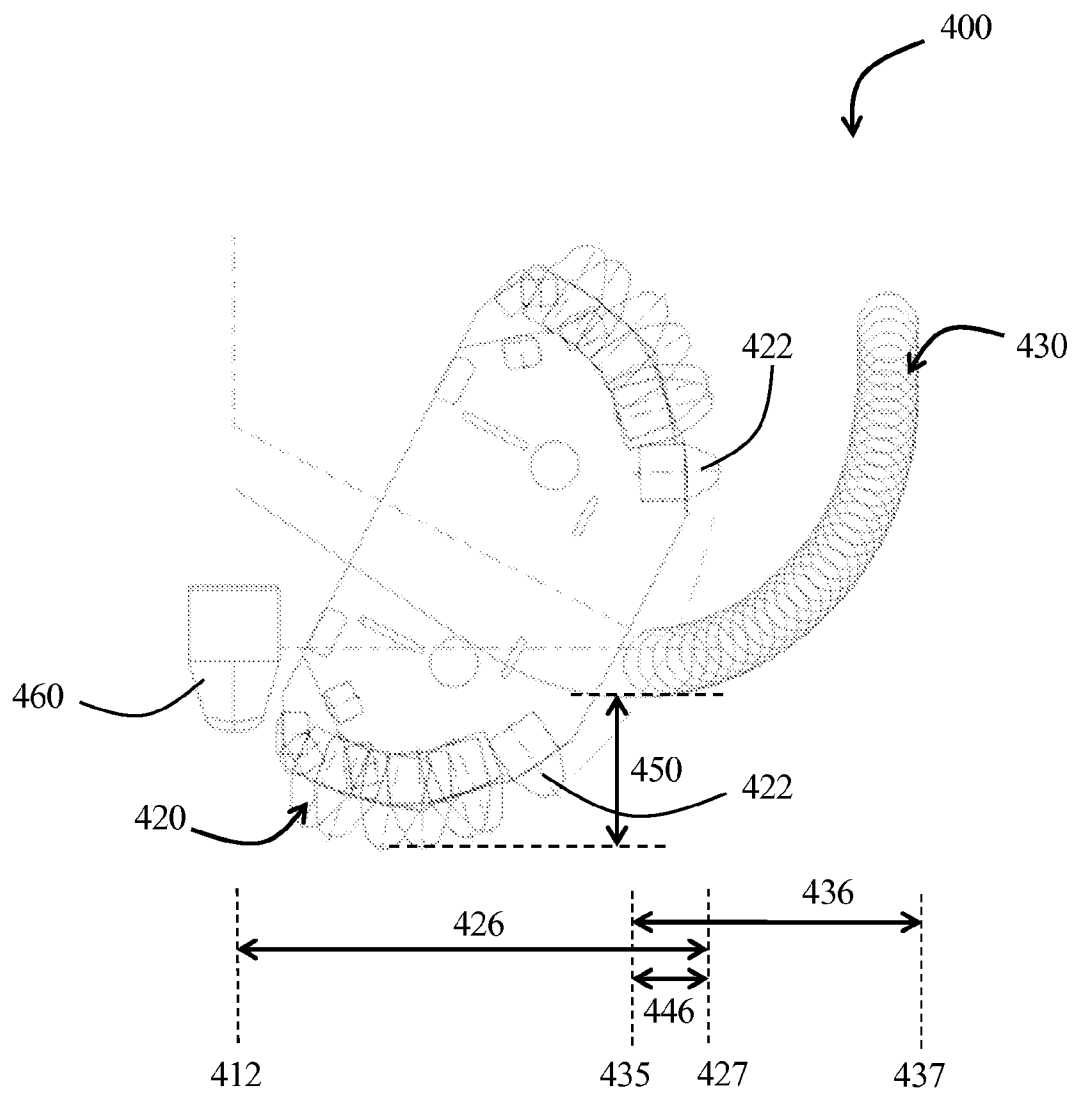


FIG. 15

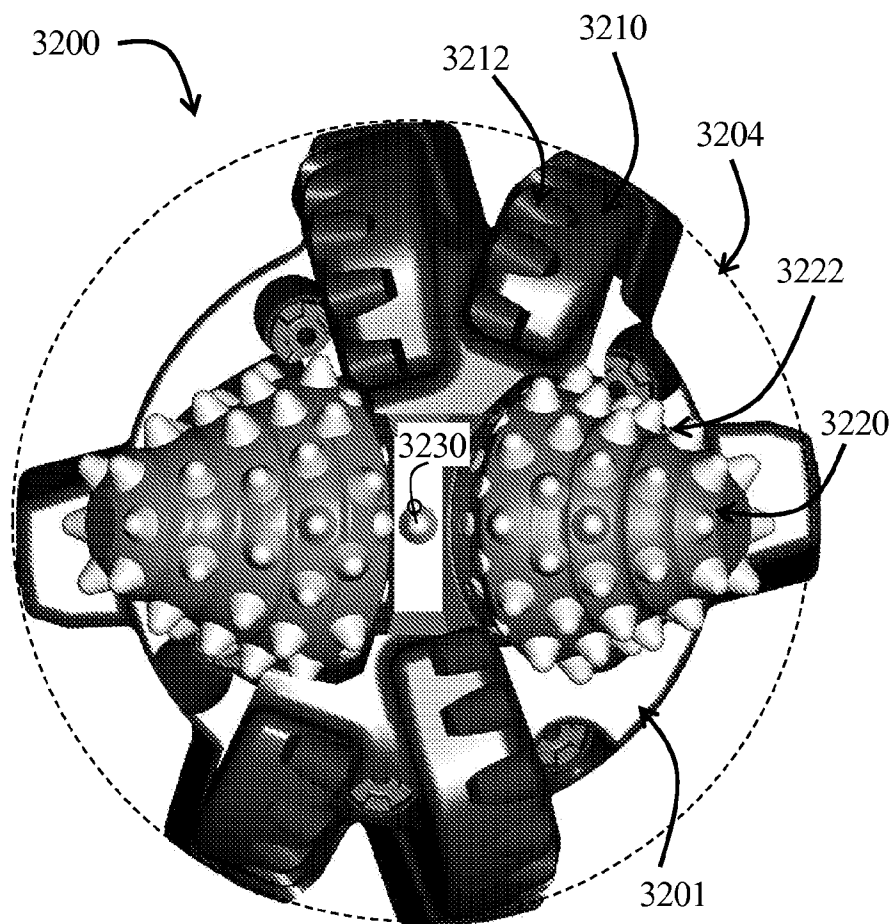


FIG. 16

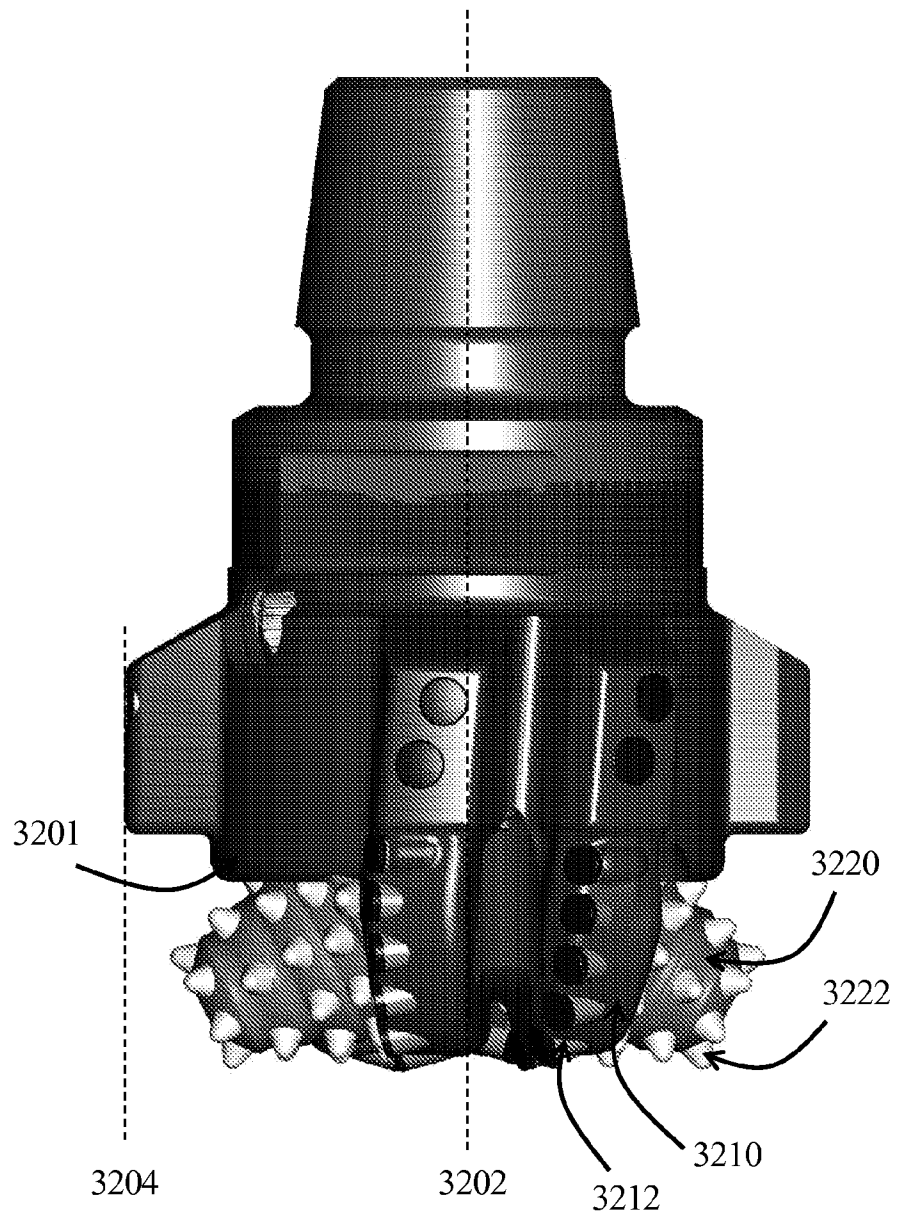


FIG. 17

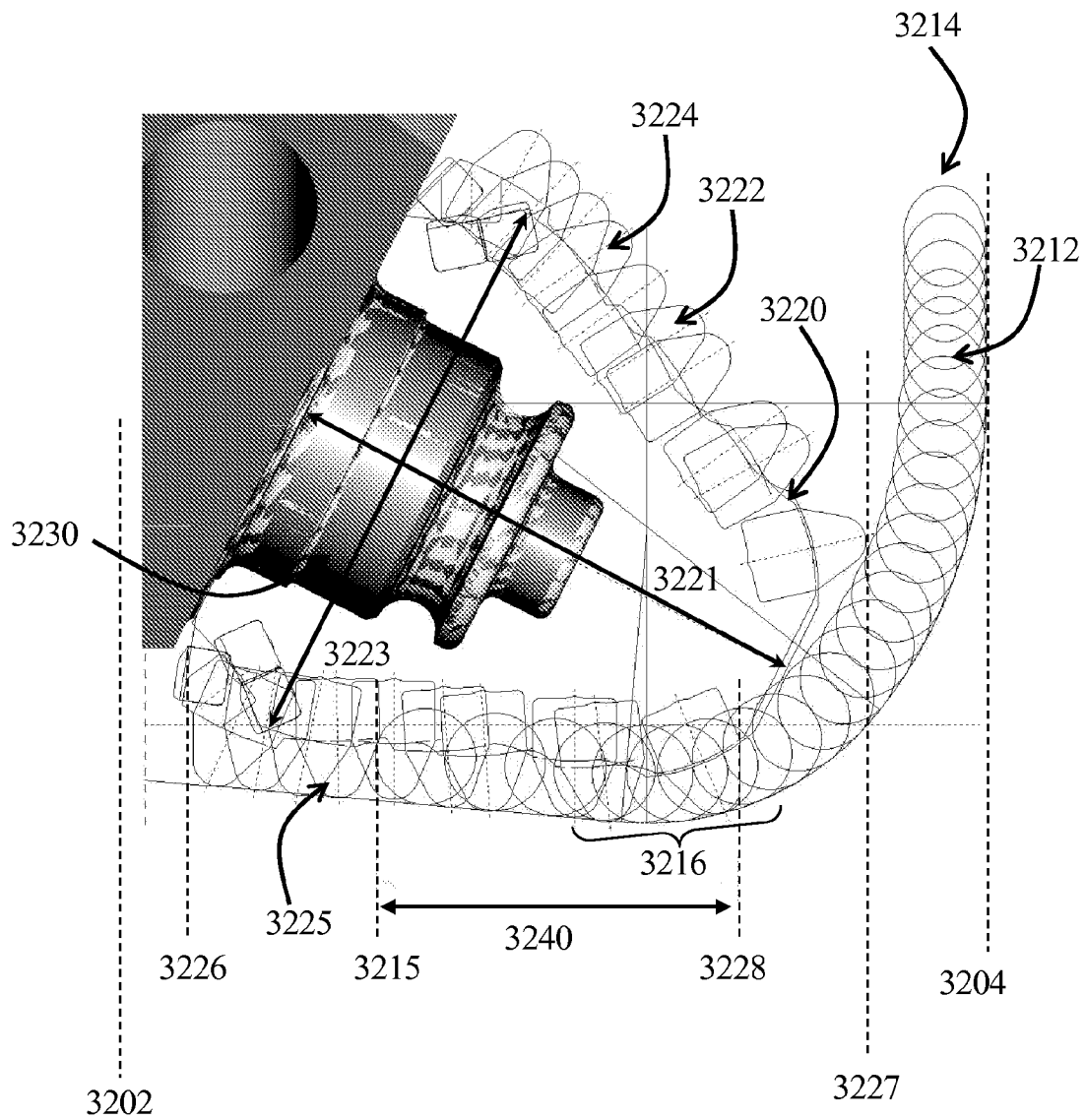


FIG. 18

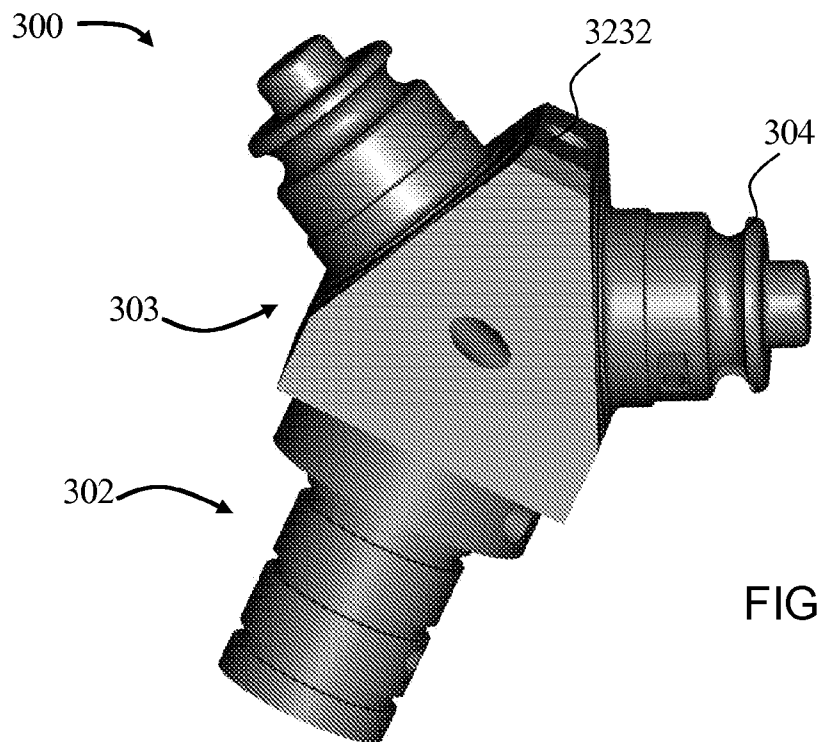


FIG. 19

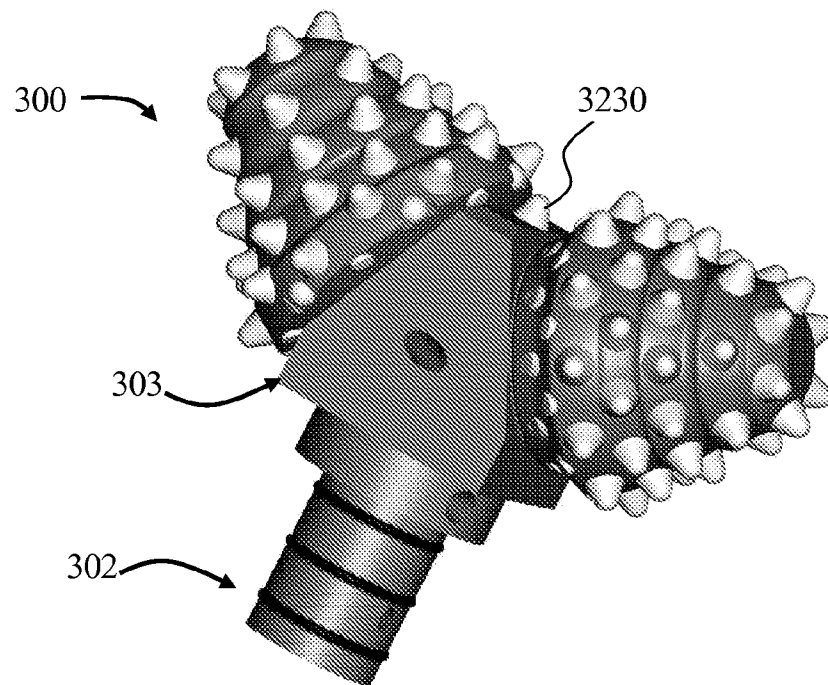


FIG. 20

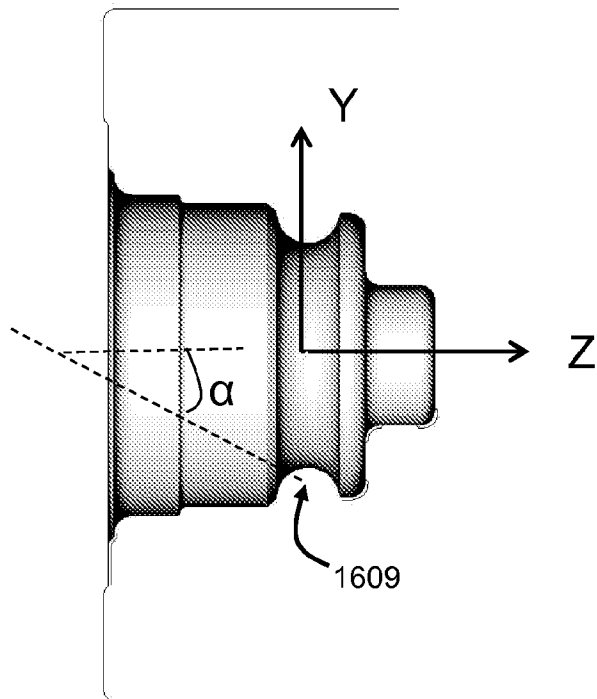


FIG. 21

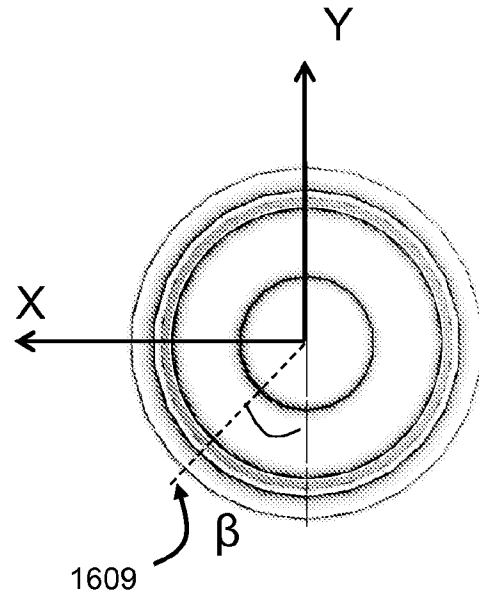


FIG. 22

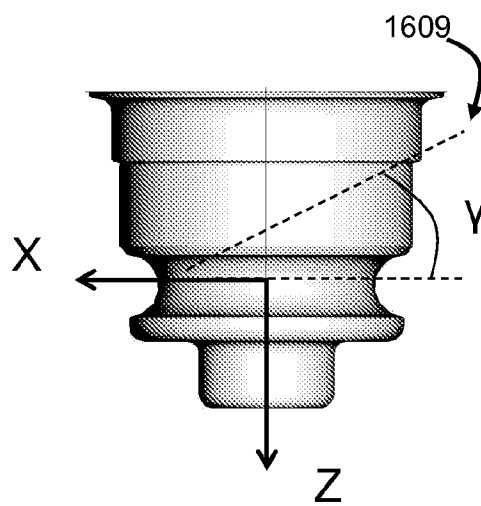


FIG. 23

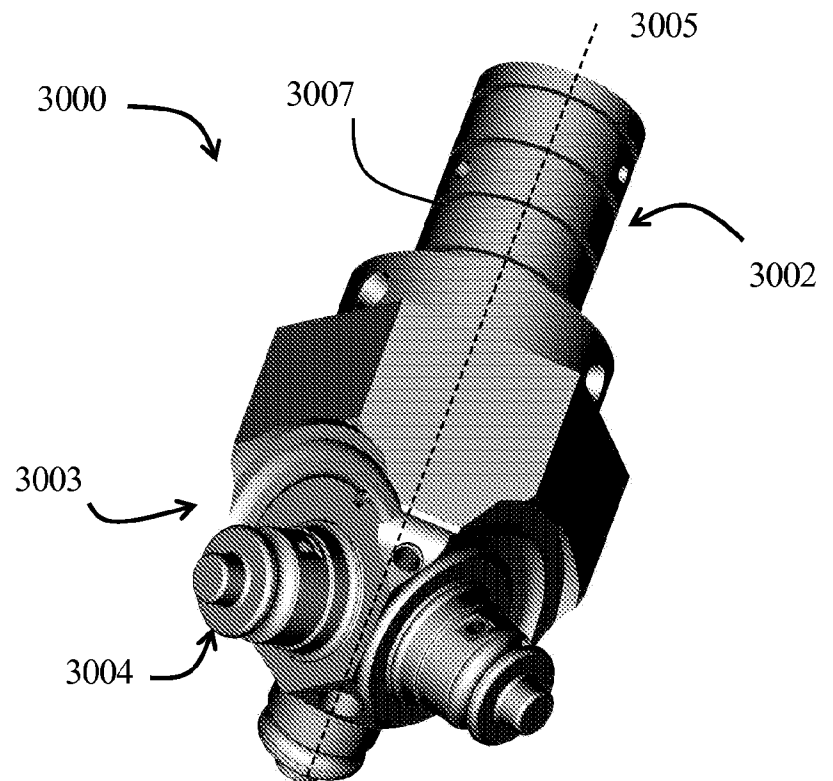


FIG. 24

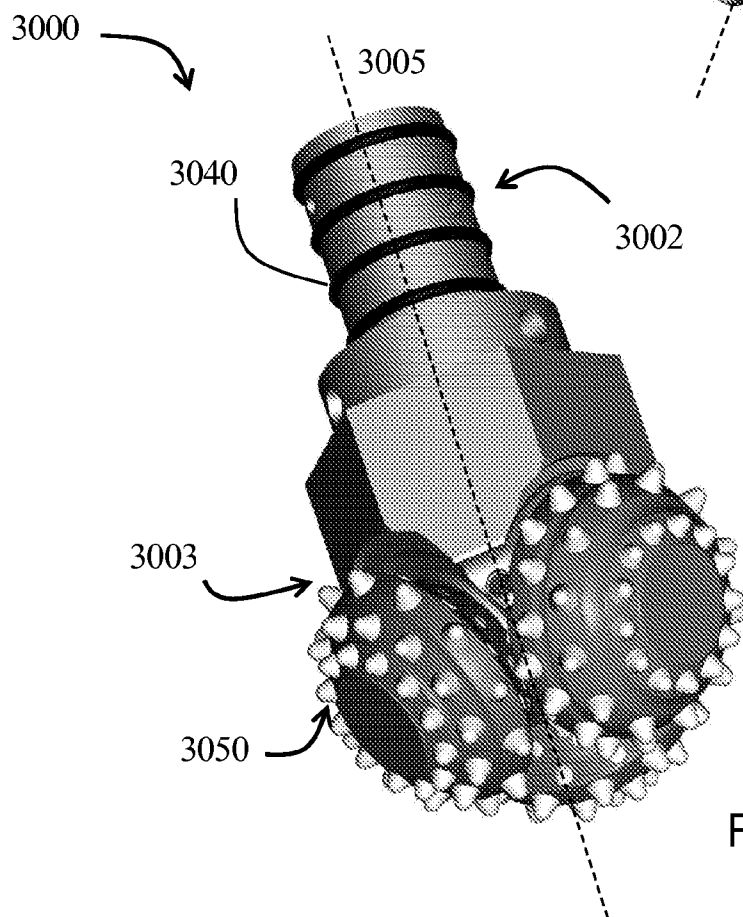
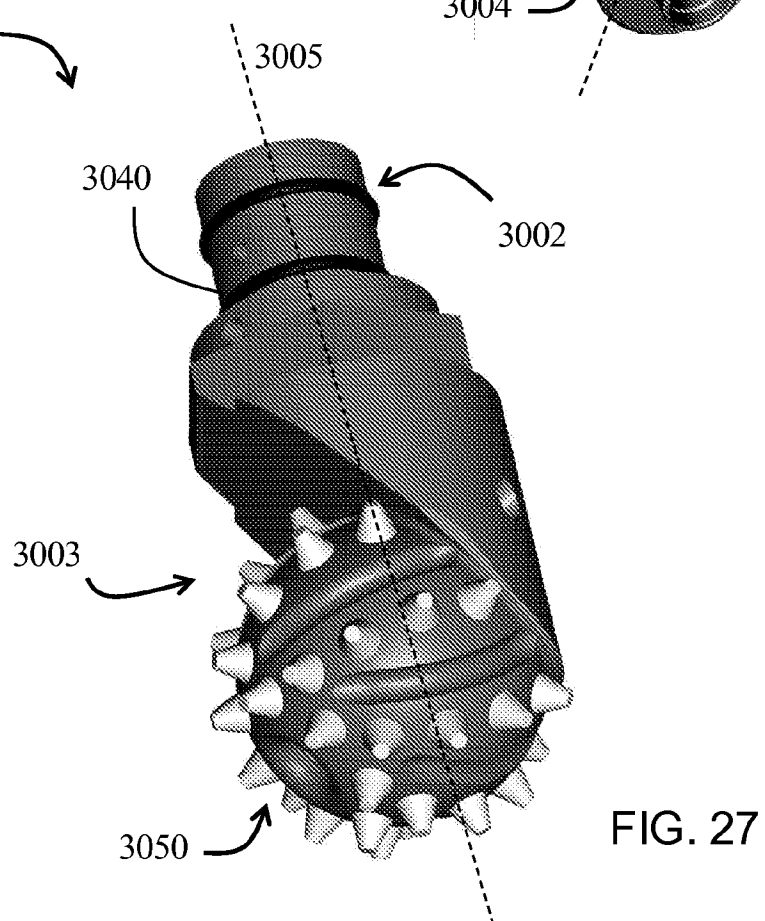
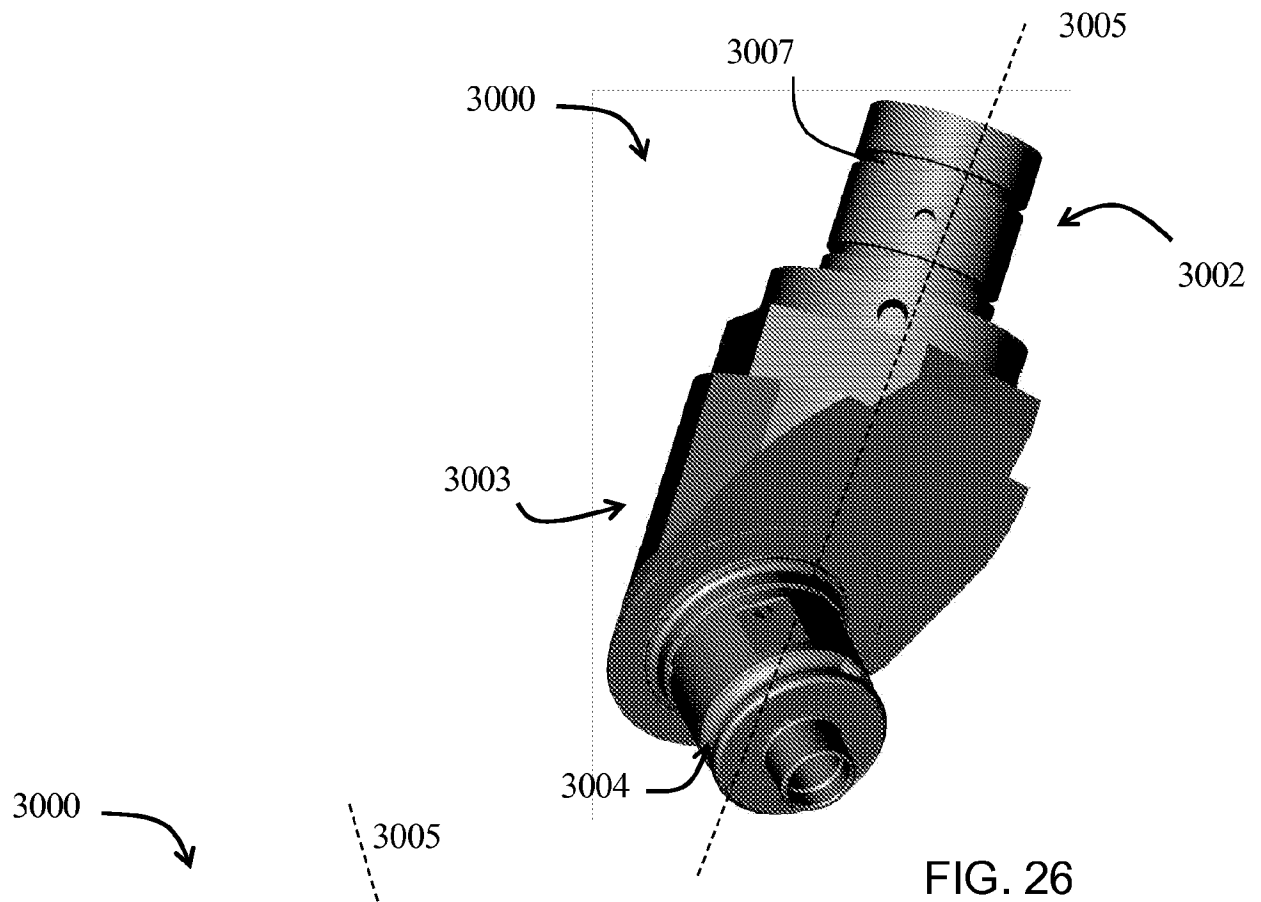


FIG. 25





## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2014/070698****A. CLASSIFICATION OF SUBJECT MATTER****E21B 10/14(2006.01)i, E21B 10/16(2006.01)i, E21B 10/62(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

E21B 10/14; E21B 7/00; E21B 10/36; B23P 15/28; E21B 10/00; E21B 10/08; E21B 10/26; E21B 10/16; E21B 10/62

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords: hybrid drill bit, journal, blade, lock, roller cone, o-ring, lubrication, material, torque

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                    | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 2011-0162893 A1 (ZHANG, ZHEHUA) 07 July 2011<br>See paragraphs [0048]–[0059], [0072] and figures 4A, 7C, 13C, 15A. | 1–9, 12–13, 15–20     |
| Y         |                                                                                                                       | 10–11                 |
| A         |                                                                                                                       | 14                    |
| Y         | US 2011-0024197 A1 (CENTALA et al.) 03 February 2011<br>See paragraph [0082] and figure 15.                           | 10–11                 |
| A         | US 2009-0272582 A1 (MCCORMICK et al.) 05 November 2009<br>See paragraphs [0021]–[0029] and figures 1–4.               | 1–20                  |
| A         | US 2009-0126998 A1 (ZAHRADNIK et al.) 21 May 2009<br>See paragraphs [0029]–[0056] and figures 1–6.                    | 1–20                  |
| A         | US 6412579 B2 (FIELDER, COY M.) 02 July 2002<br>See abstract and claim 1.                                             | 1–20                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

31 March 2015 (31.03.2015)

Date of mailing of the international search report

**31 March 2015 (31.03.2015)**

Name and mailing address of the ISA/KR

International Application Division  
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Facsimile No. ++82 42 472 7140

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2014/070698**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                                                                                                                                                                                   | Publication<br>date                                                                                                                                                                                                          |
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